

9950-901

DOE/JPL-954527-83/24

Distribution Category UC-63

(NASA-CR-173755) INVESTIGATION OF TEST  
METHODS, MATERIAL PROPERTIES, AND PROCESSES  
FOR SOLAR CELL ENCAPSULANTS Annual Report  
(Springborn Labs., Inc., Enfield, Conn.)  
128 p HC A07/MF A01

M84-28209

Unclas  
19797

CSSL 10A G3/44

INVESTIGATION OF TEST METHODS,  
MATERIAL PROPERTIES, AND PROCESSES  
FOR SOLAR CELL ENCAPSULANTS

SEVENTH ANNUAL REPORT

1983

JPL Contract 954527  
Project 6072.1

For

JET PROPULSION LABORATORY  
4800 Oak Grove Drive  
Pasadena, California 91103

ENCAPSULATION TASK OF THE LOW-COST  
SILICON SOLAR ARRAY PROJECT

The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and is part of the Photovoltaic Energy Systems Program to initiate a major effort toward the development of cost-competitive solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

Paul B. Willis

SPRINGBORN LABORATORIES, INC.  
Enfield, Connecticut 06082



(+)

TECHNICAL CONTENT STATEMENT

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights."

## TABLE OF CONTENTS

	<u>Page No.</u>
I. SUMMARY . . . . .	I-1
II. INTRODUCTION . . . . .	II-1
III. AGING AND DEGRADATION STUDIES . . . . .	III-1
A. Thermal Aging . . . . .	III-6
B. RS/4 Exposures . . . . .	III-10
C. RS/4 85°C Exposure . . . . .	III-14
D. CER (Controlled Environment Reactors) . . . . .	III-16
E. Outdoor Photothermal Aging Devices (OPT) . . . . .	III-17
F. Metal Catalyzed Degradation . . . . .	III-19
IV. WATER ABSORPTION . . . . .	IV-1
V. PRIMERS AND ADHESIVES . . . . .	V-1
VI. SOILING EXPERIMENTS . . . . .	VI-1
VII. CORROSION PROTECTION . . . . .	VII-1

APPENDIX A - TABLES

APPENDIX B - FIGURES

I. SUMMARY

Springborn Laboratories, Inc. is engaged in a study of evaluating potentially useful low cost encapsulation materials for the Flat-Plate Solar Array project (FSA) funded by the Department of Energy and administered by the Jet Propulsion Laboratory. The goal of the program is to identify, evaluate, test and recommend encapsulant materials and processes for the production of cost-effective, long life solar cell modules. During the past year technical investigations have included studies of aging and degradation of candidate encapsulation materials, continued identification of primers for durable bonding of module interfaces, continued evaluation of soil resistant treatments for the sunlit surface of the module and testing of corrosion protective coatings for use with low cost mild steel substrates.

In order to assess the relative stability of individual polymers and to determine the effectiveness of varying formulations, Springborn Laboratories is conducting a program of accelerated aging and life predictive strategies that should be useful for: (a) generating empirical and practical data relating to longevity, and (b) generating data that may be used in a scheme to predict properties as a function of exposure time and condition. The conditions being used for the exposure of candidate encapsulation materials include thermal aging (air oven), RS/4 (50°C) sunlamp exposure, RS/4 at 85°C, Controlled Environment Reactors (JPL equipment), Outdoor Photothermal aging racks, and the effects of metal catalyzed degradation. The RS/4 and Controlled Environment Reactors employ mercury lamp light sources and are filtered to confine the output to terrestrial ranges only.

Thermal aging was evaluated on the four candidate pottants, EVA, EMA, Aliphatic Polyurethane (PU) and Polybutyl Acrylate (BA). The specimens were aged at three temperatures (80°C, 105°C and 130°C) and in atmospheres of both air and nitrogen to discriminate between plain thermal instability (thermolysis) and reaction with heat and oxygen (oxidation). Specimens were evaluated at intervals throughout a 1,000 hour exposure period. The candidate pottant compounds EVA, EMA and Butyl acrylate

have been found to be surprisingly stable enduring 1,000 hours at 130°C with little change in useful properties, although there is some evidence indicating the volatile loss of UV absorber. The aliphatic polyurethane pottant is the most thermally degradable candidate examined and terminates within 100 hours at 130°C. At 105°C, this material still shows signs of degradation and it becomes darkly colored. This candidate should not be used in modules applications where high temperatures are anticipated.

R/S 4 Sunlamp exposure (50°C) is a widely used industrial method of assessing the relative stability of plastics to the degrading effects of ultraviolet light. The results are useful for the ranking and comparison of the stabilities of polymeric materials and the effectiveness of additives and formulations. The EVA formulation A9918 is performing extremely well and a prototype formulation has only just begun to degrade after 40,000 hours of exposure. In comparison, the unstabilized base resin degrades within 500 hours. Based on a rough calculation of accumulated UV energy, one year of RS/4 exposure is approximately equal to 6.7 years of outdoor exposure in a hot climate. This indicates that the EVA specimen has survived the equivalent of 30 years of outdoor exposure. The other pottants and most of the encapsulation materials of interest show no signs of degradation and survive for long periods of time in this test. This technique is useful for assessing the relative performance of marginally stable materials, however, very light-stable materials require years before the onset of degradation occurs.

Due to the low acceleration factor of the RS/4 test, the temperature was raised from 50°C to 85°C in another series of exposures intended to give useful information in shorter periods of time. Despite the increase in temperature, the candidate pottants still perform extremely well in this exposure condition, enduring 4,000 hours to date with no significant property changes. Unstabilized EVA and formulations without HALS<sup>a</sup> type stabilizers degraded severely within the first 1,000 hours. Experimental evidence clearly indicates that ultraviolet screening alone is not enough to stabilize the EVA polymer and HALS stabilizers appear to be essential for the long life of EVA formulations.

---

a. Hindered amine light stabilizer.

Controlled Environment Reactors (CER) are medium pressure mercury lamp devices with a water spray cycle that were designed, built and supplied by JPL. They are operated at 50°C and have a solar ultraviolet acceleration factor of 30 suns. This condition proved to be more severe than the preceding types of exposure and resulted in depolymerization of cured EVA pottant within 4,000 hours. Experimental evidence suggests that this degradation was preceded by extractive loss of stabilizers from the polymer. The most accelerated aging test yet investigated is the Outdoor Photothermal Aging device (OPT) that combines elevated temperatures (70°, 90°, 105°C) with natural sunlight, rainwater, and the other elements of outdoor exposure. These devices were found to be particularly severe, especially at the highest temperature, and resulted in the decomposition of all candidate pottants within a 2,000 hour period of time. Experimental formulations designed to test individual stabilizers degraded very rapidly. The polymer degradation appears to be different in this condition than observed with the others. Instead of depolymerization and flow, the OPT aged compounds all have high gel content and no discoloration, but lose their mechanical properties and acquire a "cheesy" consistency. This method is useful for generating aging data within fairly short periods of time.

Metal Activation: due to the intimate contact between pottants and metals in solar module applications, experiments were conducted to determine if any catalytic degradation effects were observable. Copper is particularly known for accelerating the oxidation of polyolefins and other polymers. This was definitely found to be the case with the candidate pottant compounds. Heating the pottants (105°C) in the presence of copper mesh resulted in rapid (600 hours) discoloration and loss of properties in all materials. Although copper exposure poses no problem during the 150°C (20 minute) lamination cycle, long term aging in the presence of copper may impose a temperature limit for modules in service. The use of metal deactivators and silane treatment of the metal surface definitely extend the lifetime, however, it is strongly suggested that exposure to metallic copper be avoided. No reactions are observed with aluminum, 60/40 solder nickel, silver or titanium.

Some general conclusions may be drawn from the results of the accelerated aging experiments to date. These are:

- o The severity of the aging conditions examined to date is:  
 RS/4 (least) < RS/4-85°C < Thermal Aging, 105°C <  
 Controlled Environment Reactors (CER) < Outdoor Photothermal reactors,  
 << Copper catalyzed degradation, 105°C (worst)
- o The first property to change is most frequently color (yellowing).
- o The properties least affected are mechanical and dielectric.
- o In terms of modeling, the degradation curves are predominantly "induction period" type, and very few resemble first-order behavior.

Due to their deployment in an outdoor environment, PV modules and their component parts will be exposed to water in the form of humidity, rain, dew, etc. This could conceivably give rise to problems resulting from water absorption. Candidate pottant materials were immersed in distilled water at temperatures ranging from 20°C to 90°C and the weight changes recorded on a weekly basis. The EVA, EMA and Butyl Acrylate pottants show equilibrium water absorptions in the range of 0.2 to 0.7 weight percent, increasing steadily with the increase in temperature. At 90°C, steady increases in absorption are noticed for EVA and EMA suggesting hydrolysis in the two polymers, the EVA being noticeably more effected than the EMA. The aliphatic urethane is very much more sensitive to hydrolysis than any of the other resins tested. Even at temperatures as low as 20°C there are signs of chemical degradation. At the 90°C condition, the hydrolytic attack on this compound is very rapid and the resin appears to be slowly dissolving into the water phase. Although these experiments point out some intrinsic sensitivity of these materials, it is not known what impact this may have in actual module operation.

Primers were evaluated for effectiveness in bonding candidate pottants to outer covers, glass and substrate materials. The bond strengths were determined by standard methods and measured in pounds per inch of bond line. Successful primers were also tested after two weeks of water immersion and two hours of boiling water. Good primers have been identified for bonding

EVA (9918) to almost all candidate materials . Despite the similarity in chemistry, the EMA is much more difficult to bond and, to date, successful results have only been obtained with glass and mild steel. The polyurethane casting syrup has been effectively bonded to Sunadex, Tedlar and Korad , but additional work is required on steel and polyester. The butyl acrylate syrup is the most difficult pottant of all to bond and is additionally complicated by its inherently low tensile strength. Bonds to Tedlar and Sunadex glass that survive the water immersion and boiling tests have been achieved, however they are both low in bond strength, and do not exceed 1 to 2 pounds per inch of width.

Although the raw material cost is low, priming is an expensive step due to the application technology. Efforts were made to eliminate this step with the use of self-priming formulations. Two EVA, and one EMA formulation were compounded with the active silane primer and subsequently tested for the bond strength to glass. The results were excellent, resulting in bonds of 30 to 50 lbs/in., even when the silane was used at levels as low as 0.05%.

An experimental program continued to determine the usefulness of soil resistant coatings. These coatings are intended to be surface treatments applied to the sunlight side of solar modules and function to prevent the persistent adhesion of soil to the surface, aid in its removal, and consequently keep the power output high. These treatments have been applied to "Sunadex" glass, Tedlar and oriented acrylic film. The treatments are based on silicone, acrylic, and fluorosilane chemistries. After twenty four months of outdoor exposure a fluorosilane treatment designated E-3820, was found to be the best coating for all three outer surfaces and result in significantly better soil resistance than the controls. This material still appears to be active after two years, whereas the others have all lost their effectiveness. Based on standard solar cell measurements, the improvement in power output using this treatment is estimated to be about 1% for Sunadex glass, 3.8% for Tedlar and 3.9% for Acrylar.

The last technical topic concerns the corrosion protection of steel. Mild steel is a readily available and easily worked material that holds the promise of being a cost-effective substrate. Its major deficiency is that of corrosion sensitivity. Experiments are underway to assess the durability and cost effectiveness of coatings for protection of steel. Test specimens were prepared with a variety of films, paints and pottants and then exposed to 35°C Salt Spray (ASTM B-117) and outdoor weathering conditions. The specimens were evaluated for degree of corrosion, delamination and other destructive effects at regular intervals. The salt spray and outdoor results generally correlated well, except for the degree of attack, which was much more severe in the heated salt fog. Untreated control specimens survived three hours under salt spray before extensive corrosion became apparent.

A new corrosion resistant primer coat called Alseal-518, an aluminum modified ceramic frit, was found to give very good results. The coating is applied to the steel from a water solution at about a 1 mil thickness and then baked. The estimated cost is 7¢/ft<sup>2</sup>/mil. The primer coat by itself proves to be surprisingly corrosion resistant and has lasted 3,300 hours to date with only a light coating of corrosion product, but no rust. Primed steel specimens were prepared with a variety of topcoats, including urethane, silicone and fluorinated enamel. The urethanes appear to be surviving the best and after 3,300 hours the surfaces not exposed directly to the salt spray show no change whatsoever. Top surfaces show signs of small blisters in some areas, however this may be due to inadequate adhesion. Future experiments will use silane primers to improve the bond strength. Overall, the Alseal-518 coating appears to be one of the most effective corrosion barriers identified.

## II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.70 per peak watt ( $\$70/\text{m}^2$ ) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirement, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per  $\text{m}^2$  in midday sunlight, the capital cost of the modules may be calculated to be \$70.00 per  $\text{m}^2$ . Out of this cost goal, only 20 percent is available for encapsulation due to the high cost of the cells, interconnects, and other related components. The encapsulation cost allocation<sup>a</sup> may then be stated as \$14.00 per  $\text{m}^2$  which included all coatings,

a. JPL Document 5101-68

The former cost allocation for encapsulation materials, was \$2.50/r<sup>2</sup> (0.25/ft<sup>2</sup>) in 1975 dollars, or \$3.50/m<sup>2</sup> (\$0.35/ft<sup>2</sup>) in 1980 dollars. The current cost allocation of \$14/m<sup>2</sup> is an aggregate allocation for all encapsulation materials including an edge seal and gasket.

pottants, and mechanical supports for the solar cells.

Assuming the flat-plate collector to be the most efficient design, photovoltaic modules are composed of seven basic construction elements. These elements are (a) outer covers; (b) structural and transparent superstrate materials; (c) pottants; (d) substrates; (3) back covers; (f) edge seals and gasket compounds; and, (g) primers. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Throughout this program, extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

<u>Construction Elements</u>	<u>Approximate Cost Allocation* (\$/m<sup>2</sup>)</u>
Substrate/Superstrate (Load Bearing Component)	7.00
Pottant	1.75
Primer	0.50
Outer Cover	1.50
Back Cover	1.50
Edge Seal & Gasket	1.85

\*Allocation for combination of construction elements: \$14/m<sup>2</sup>.

From the previous work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The first page of Appendix A (Table I) gives the status of

candidate encapsulation materials identified to date. These materials are thought to be the most satisfactory for use as the construction element indicated.

In addition to materials, two encapsulation processes are being investigated:

- 1) Vacuum bag lamination
- 2) Liquid Casting

The suitability of these processes for automation is also being investigated. However, the selection of a process is almost exclusively dependent on the processing properties of the pottant. This interrelationship may have a significant influence on the eventual selection of pottant materials.

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide a maximum light transmission to the cell surface and optimize power output.

This report presents the results of the past year which has been directed at the continuing development and testing of pottants and other components.

The topics covered in this report are as follows:

1. The empirical study of the thermal and photothermal stability of candidate encapsulation materials, with an emphasis on pottants.

2. Continued studies of adhesion in order to identify the best primer and process for the high reliability bonding of module components.
3. An evaluation of soil resistant coatings for application to module surfaces in order to keep the power output high.
4. A continued investigation of corrosion protective coatings for use with mild steel to give a low cost long life substrate.

III. AGING AND DEGRADATION STUDIES

The candidate encapsulation materials being investigated in this project are intended for the construction of solar cell modules for terrestrial deployment and consequently must be capable of enduring the operating temperatures, insolation, precipitation and other elements of the outdoor exposure in the geographical region selected. Although the severity of these conditions may be fairly accurately gauged (climatic atlas, weather records, etc.) the lifetime and performance of individual materials or combinations of materials is not as easily assessed. The chemical pathways and rates at which materials age in outdoor exposures are very complex and predictive techniques often turn out to be inaccurate.

Many degradation processes, including those that ultimately result in the failure of polymers are associated with thermal, chemical, mechanical, electrical, and radiation induced disruption of chemical bonds. These stresses, either alone or in combination, can produce certain active chemical intermediates that may continue to react further with the polymer chain and result in macroscopic changes in the electrical, mechanical and optical properties of the material. In most polymers, the degradation mechanisms involve the stress-induced separation of electrons from the covalent bond that results in bond rupture and the formation of two free radical intermediates. These active free radicals may then propagate a series of reactions in which oxidation, discoloration, bond scission and loss of physical properties result.

The degradation of polymeric materials in outdoor weathering is caused primarily by sunlight, especially the ultraviolet component. In actuality, the deteriorating effect of light is usually enhanced by the presence of oxygen, moisture, heat, abrasion, etc. and in many cases may be referred to as photo-oxidation, resulting from the combined effects of oxygen and sunlight.

### III-2

Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 290 nm before it reaches the surface of the earth. Thus, ultraviolet effects on plastic result primarily from wavelengths of approximately 290-400 nm, which constitute less than 4 percent of the total solar radiation reaching the earth.

The shorter the wavelength of light the greater is its potential to produce a chemical change in material. This energy must first be absorbed in order for damage to occur.

Plastics vary considerably in their ultraviolet absorbing properties, but few are completely transparent in the 290 to 400 nm range. Once the radiant energy has been absorbed, the likelihood of chemical action will depend on the degree of absorption and the stability of the chemical bonds in the polymer. The induced chemical modifications are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation and transparency.

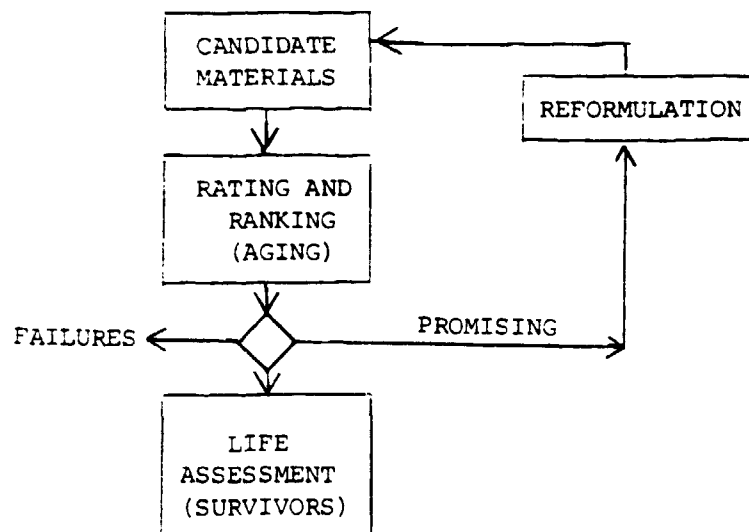
The degradative effects of these environmental stresses may be effectively inhibited by the incorporation of specially formulated additives to the polymer. Compounds that serve as ultraviolet light absorbers, antioxidants, hydroperoxide decomposers, metal deactivators, etc. may result in dramatic improvements in the service life of polymeric systems. Regardless of the inherent sensitivity of the polymer or the effectiveness of the additives and formulation, the question of lifetime under service conditions remains an important question.

Accelerated tests are frequently used to assess long term aging effects and compare the effectiveness of stabilizers in providing improved protection against environmental deterioration. Typically, properties such as tensile strength, elongation at break, apparent modulus, resistance to flex cracking and other properties are measured on samples aged for known periods of time under specified conditions. These tests are useful for determining the relative stability of polymers and formulations, but correlation with actual service is not always accurate.

This is especially true for outdoor aging where the conditions of weathering cannot be precisely simulated or accelerated in the laboratory. Changes in the ratio of crosslinking to chain scission, temperature variations, differing oxygen concentrations, ultraviolet flux, dark cycle reactions, etc. add to the difficulty of correlation and performance prediction. Accelerated tests are useful, however, for the relative ranking and rating of materials and can provide approximate acceleration factors that are useable over a certain range.

In order to assess the relative stability of individual polymers and to determine the effectiveness of varying formulations, Springborn Laboratories is conducting a program of accelerated aging and life predictive strategies that should be useful for: (a) rating, ranking and reformulating candidate encapsulation materials, (b) generating practical data that relate to material performance under use conditions, and (c) generating data that may be useful in some type of predictive manner for life assessment.

These goals are being met by using the scheme presented in the following diagram:



This method is intended to serve as a multipurpose data source.

### III-4

The stresses to which materials are exposed consist of the following, either singly or combined:

- (a) Thermal stress (heat aging)
  - . in inert atmosphere
  - . in air
- (b) Ultraviolet stress (UV exposure)
- (c) Hydrolytic stress (water exposure)
- (d) Catalytic stress (metal catalyzed oxidation)
- (e) Combined stresses (any of the above together)

The effects of these stresses on the candidate encapsulation materials is determined by measuring specific properties as a function of time. These properties were selected for their relevance to module service life and were chosen from four categories considered to be potentially life-limiting, as follows:

- . Mechanical: tensile strength, elongation, gel content, modulus
- . Optical: yellowing, haze, optical transmission from 0.4 to 1.1 microns
- . Chemical: loss of stabilizers, degradation, corrosion of interconnect metalization, metal catalyzed reactions, outgassing
- . Dielectric: field stress degradation, decay of breakdown strength, leak current, loss of electrical isolation

For the evaluation of individual materials and/or combinations of materials, types of exposure conditions are being used, as follows:

1. Thermal Aging: This method employs the exposure of specimens to heat in an air oven. Atmospheres of air and nitrogen are both used.
2. RS/4 Exposure: This method uses the well accepted RS/4 sunlamp as a source of ultraviolet radiation and specimens are exposed on a rotating wheel beneath the lamp at a temperature of 50°C. Both dry and "wet" cycles (with water spray) are used.

3. RS/4-85°C: This is the same exposure as (2.) except the temperature has been increased to include an additional stress.
4. Controlled Environment Reactors: These are devices designed and supplied by JPL and consist of chambers containing high power medium pressure mercury arc lamps and a water spray nozzle.
5. Outdoor Photothermal Reactors: These devices use natural sunlight as the light (UV) source and utilize heat to accelerate natural photodegradation reactions.
6. Metal Catalyzed Oxidation: This condition is essentially thermal aging in the presence of metal (copper) which is known to rapidly accelerate degradation reactions.

A number of approaches to data modeling may be considered, the simplest being first order behavior in which the log of the property being measured is linear over time. This relationship may be used easily for life prediction, especially when the reaction rate is proportional to the temperature (Arrhenius relationship). Polymer degradation is frequently a complex relationship of many competing chemical reactions, however, and may shift dramatically with subtle changes in temperature, light intensity, additives, etc. The behavior most frequently observed is the "induction period" type in which the degradation rate suddenly changes and the property vs. time curve shows a sharp downward trend. The tie to the onset of this change is the induction period and is often used to measure the efficiency of antioxidants. As an alternative to these two, the change in properties under actual module conditions gives useful information of an empirical nature. This empirically generated data may possibly be modeled using the following considerations: (1) characterize the materials, (2) characterize the stress, (3) select the property that changes, (4) correlate the data, (5) surmise the mechanism, and finally (6) predict the time to failure.

#### A. Thermal Aging

Thermal aging of the candidate pottant compounds is an ongoing program at Springborn Laboratories, and is intended to generate data concerning the purely thermal degradation effects on these polymeric materials. Due to the fairly high operating temperatures of PV modules and the long life that is required for acceptable performance, it is desirable to know the effects of heat alone. The data resulting from this study may possibly result in useful information concerning the performance of these pottants, such as; upper level use temperature, color formation, volatile loss of stabilizers, loss of gel content, decrease of molecular weight, loss of tensile strength, and other factors pertinent to the integrity of a PV module.

Heat aging is one of the simplest accelerated tests for determining polymer stability and the effectiveness of formulations in resins intended for service at elevated temperatures. Specimens of the candidate compounds are heated at known temperatures for known periods of time and examined for appearance, mechanical properties, chemical composition, etc. Other indications of the stability of the composition may be drawn from measurements of plasticity, solution viscosity and the formation of insoluble gel or the loss of cure in vulcanized systems.

This exposure involves the simple thermal aging of test specimens in a circulating air oven at varying times and temperatures. All the tests are conducted in sealed jars to prevent the abnormal loss of volatile stabilizers that is often encountered in forced air ovens and also to prevent cross-contamination of materials.<sup>a</sup> Candidate encapsulation materials are being exposed at temperatures of 60°C, 80°C, 105°C and 130°C in atmospheres of both air and nitrogen. The first three of these temperatures are close to the worst case temperatures that may be expected for in modules mounted in open air (60°C), roof top mounted (80°C), and solar cell hot spotting (105°C). The highest temperature, 130°C, is being used to provide an upper acceleration

---

a. This also represents the "hermetic" or non-breathable design of module in which additives are prevented from diffusing out. Volatile losses in open ovens, representing "breathable" designs will be evaluated in future experiments.

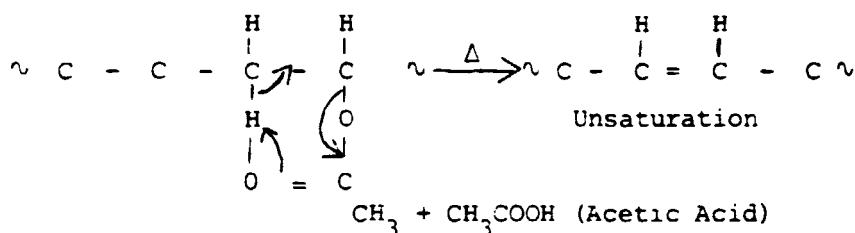
limit. Exposure in both air and nitrogen in the absence of light should also provide information concerning the inherent heat stability of compounds with and without oxidation reactions and without photo-induced reactions. Within narrow temperature ranges where the degradation rates at different temperatures may be plotted in a linear fashion with reasonable accuracy.

Data for 1000 hours of exposure is given for three temperatures and five candidate pollutants. The temperatures used in this study are 80°C, 105°C and 130°C. The four pollutants are EVA (A9918), Tables 2 through 7 ; EMA (13439), Tables 8 through 13 ; Polyurethane Z-2591, Tables 14 through 19 ; Poly(butyl acrylate), Tables 20 through 25. Data for 60°C exposures is not given in this report due to the long exposure times that have not yet been completed at this temperature.

EVA, compound A9918, is the first material reported. At the 1,000 hour exposure point, the properties of this EVA are essentially unchanged at 80°C, however there is a slight increase in gel content and decrease in swell ratio, as there is at 105°C and 130°C. This suggests that residual cure reaction may still be taking place due to remaining peroxide activity although this reaction is not usually observed at temperatures in this range. At the 105°C condition there is similarly no significant change in material properties.

The mechanical properties such as tensile strength, modulus and elongation are virtually unchanged, as is the gel content and swell ratio. The color has shifted from a clear water white (at 130°C) to a perceptible yellowish tint, but this is an absorption in the area of the spectrum where there is little power conversion in crystalline silicon cells. This yellow color is measured by spectroscopy and is reported at %T at 400 nm. One other change is also beginning to show decrease in the UV cutoff wavelength. In the 105°C and 130°C conditions the UV cutoff wavelength is slowly shifting down. This change suggests that the UV screening additive is being lost by volatilization, however, this must be verified by analysis. The only other explanation is that the UV absorber is oxidizing with consequent loss of its absorbing property.

At 130°C, changes in EVA become more noticeable. The physical properties, such as tensile strength, elongation and modulus, have not changed appreciably after 400 hours exposure, however a yellow color can be noticed. This is due to a well documented reaction in EVA which is based on simple thermal degradation (thermolysis), the chemistry of which is represented as follows:



The thermal energy imparted to the molecule results in the cleavage of the acetate group and the abstraction of a hydrogen atom from the polymer backbone to yield acetic acid. This results in the formation of double bonds in the resin that (when conjugated) gives rise to the yellow color. This reaction has been shown to be approximately first order with respect to the liberation of acetic acid and has an activation energy of 30 - 40 kcal/mole. The formation of coloration at this temperature is not felt to be detrimental to the use of EVA as a pottant material, as the 130°C is well beyond the range of solar module operation.

In conclusion, the EVA pottant is remarkably stable to temperatures even as high as 130°C and may prove to be much more tolerant of conditions, such as hot-spot heating, than expected.

The EMA, Formula 13439, is also extremely stable and no changes in properties are recorded up to the 130°C condition. At 130°C, some formation of color is observed, both visibly and by spectroscopy. Although EMA does not release acetic acid as EVA does, a similar reaction involving the cleavage of the acrylic ester group is likely, as the C-O bond is less stable than the C-C bonds in the backbone of the resin. The formation of color is slightly worse in the nitrogen atmosphere than in air. This is probably due to bleaching of the color centers by oxidation in the air exposure. This color formation is not thought to impose a great penalty on cell performance due to its absorption in the blue region of the spectrum.

The only other observable change is that of UV cutoff wavelength. In EMA it is noticed that this wavelength increases the 130°C (nitrogen) condition, starts at 354 nm and increases to 370 nm. The cause of this is not known, however it may be due to the formation of a UV absorbing moiety in the polymer itself. FTIR spectroscopy is needed to confirm this and also determine if this group will have an effect on the final photostability of the polymer. Apart from these observations the EMA candidate encapsulant appears to be very thermally stable and no other major property changes are evident.

The aliphatic polyurethane, Z-2591, was comparatively the most thermally sensitive of the three candidate pottants reported so far. Even at 80°C the development of a small amount of yellow color (although faint) was noticeable at the 400 hour point. The 105°C condition brought more noticeable changes in property. Despite some fluctuations due to experimental error in the measurement of mechanical properties, the tensile strength, elongation and modulus remain substantially unchanged through the 1,000 hour exposure. Color and surface texture, however, change rapidly. Moderate color is noticeable within 100 hours, the air atmosphere condition being somewhat worse than the nitrogen exposure. Within 400 hours the urethane has developed a strong dark brown color and the surface has become very sticky from oxidation and molecular weight degradation. At 1,000 hours the specimens are in much the same condition and somewhat difficult to handle due to the surface tack. A gradual increase in swell ratio during this time also suggests that the crosslink density, or degree of cure, is slowly diminishing with time. No decrease in dielectric breakdown strength or leak current was found.

The 130°C exposure was by far the most severe. The physical integrity of the test specimens lasted to the 100 hour mark, however, at 400 hours the tensile bars had all melted to amorphous masses of dark brown sticky resin. Coloration developed within the first 25 hours and became dark within 100 hours. At 130°C, the 100 hour point is clearly the end of life for this candidate pottant due to opacity, and at 400 hours due to complete loss of physical properties. Based on these results, the use of the polyurethane pottant is

module applications where higher operating temperatures are anticipated is questionable.

The results for poly(butyl acrylate), Formulation 13870, are reported in in Tables 20 through 25. In all cases, the results for tensile strength and elongation appear to be low when compared with the control values. This is thought to be due to a batch variation in the resins from which the control measurements were made versus the batch used to prepare the thermal aging specimens. This discrepancy will be corrected by remeasuring control values for the same lot. The results are still useful, however, in that variations and trends can be noticed within the aging data. Based on this Poly(butyl acrylate) is quite thermally stable, even in the severe 130°C condition and, apart from small changes in color, there is no data to report that reflects degradation of this resin.

In conclusion, the polyolefin based pottants, EVA and EMA, are considered to have good thermal stability over the times and temperatures explored so far. The polyurethane is more questionable. The formation of color in this compound at temperatures as low as 80°C could possibly place a limitation on its use in solar module applications. All the pottants remain to be evaluated for performance over long periods of time, and the next data point is scheduled for 3,000 hours.

#### B. RS/4 Exposures

The RS/4 Sunlamp exposure condition consists of a rotating table carrying the test specimens beneath a General Electric RS type sunlamp. This lamp consists of a medium pressure mercury arc lamp in a quartz tube balasted by a tungsten filament. The assembly is mounted in an inert gas filled bulb with a reflective coating and a transmission cutoff near 290 nm. The bulb is additionally filtered with a piece of Pyrex (cutoff wavelength 300 nm) to insure the absence of spectra below the terrestrial limit. This condition is one of the most easily monitored and is widely used throughout the plastics industry for the purpose of comparative aging. This device is a modification of the test procedure ASTM D-1501, "Exposure of Plastics to Fluorescent Sunlamp" and is operated at a temperature of 50°C.

As a point of comparison, unstabilized polypropylene is physically degraded after approximately 160 hours of RS/4 radiation and unstabilized low density polyethylene is degraded after approximately 450 hours. Outdoors, the degradation rates of these polymers varies according to their location. At Enfield, Connecticut, polypropylene with no stabilizers degrades<sup>c</sup> in approximately 2,400 hours and low density polyethylene fails at about 5,000 hours. Areas where the sunlight is more intense, and there are fewer cloudy days, results in more rapid degradation. Exposure to higher temperatures is also significant; the degradation rate in polypropylene is almost doubled for every 10°C increase in temperature. Based on these actual outdoor lifetimes, approximate correlation factors can be calculated for RS/4 to outdoor weathering (about 15 for polypropylene, about 11 for polyethylene). In comparing RS/4 to Mexico City for polypropylene, the acceleration factor is approximately x18 and for polyethylene approximately x13.

Although these acceleration factors provide a useful basis of comparison, it should be remembered that considerable variations may be found between different outdoor locations and/or simulated weathering conditions. Factors affecting the degradation rates include specimen thickness, spectral distribution, heat history, additives, temperature, polymerization, catalyst impurities, etc. Due to the difference in degradation pathways, acceleration factors are also material dependent.

Another way in which an acceleration factor may be determined is by measuring the total energy in the ultraviolet range. Sunlight has approximately 4% of its total energy in the ultraviolet between the wavelengths of 295 nm and 400 nm. At air mass 1.5, with a total insolation of around 650 milliwatt/cm<sup>2</sup>, the total ultraviolet energy received is in the order of 2.34 mw/cm<sup>2</sup>.<sup>a</sup>

Measurements of the RS/4 bulbs<sup>b</sup> show that the integrated energy over the same wavelength range averages to 3.44 mw/cm<sup>2</sup>. This equals approximately 1.4 suns, however, the RS/4 lamp is on continuously, whereas, the sun averaged over the year is equivalent to only 5 hours of exposure per day. This, then, results in an overall acceleration factor of 6.7 for the RS/4 sunlamp, excluding the effect of increased temperature (50°C). Equivalently, one year of

a. Brandhorst, "Terrestrial Photovoltaic Measurement Procedures" NASA TM 7370, 1977.

b. Estey, "Ultraviolet Spectra of Mercury Lamp" JPL-10M #341-79-4712, September 4, 1979.

c. Loss of 50% of tensile strength.

outdoor exposure is accomplished in approximately 1,300 hours of RS/4. If one uses the general rule that reaction rates double for every  $10^{\circ}\text{C}$  increase in temperature, then an additional factor of 2 to 2.5 may be used to correct for temperature.

Dry RS/4 exposure at  $50^{\circ}\text{C}$  is ongoing for a large number of materials. The attached tables, numbers 26 through 30 give the status of compounds that have been under exposure for a number of pull points, or that have terminated their test periods. As with the thermal aging specimens, the properties evaluated include tensile strength at break, ultimate elongation, tensile modulus (extrapolated to zero strain) and two measurements, gel content and swell ratio, that are sensitive to changes in the crosslink density. Changes in optical properties are monitored by visual appearance, the ultraviolet cutoff wavelength and total optical transmission. No values are given for the total integrated transmission at this time due to a change in the type of equipment to be used for these measurements. The performance of these candidate encapsulants is given as follows:

<u>Table No.</u>	<u>Material</u>	<u>Performance</u>	<u>Hours</u>
26	EVA A8901C (A9918)	Some visible signs of yellowing, small surface cracks appearing. No real loss of properties.	40,000
27	EVA 14747 (coreacted UV-2098)	No change	12,000
28	PU Z-2501	Some yellow color, other properties are OK	14,000
29	Tedlar 200BS-30WH	Retained 12% of original tensile strength, 3% of modulus.	15,000
30	Scotchpar 20-CPW	Severe decrease in tensile strength and elongation.	15,000

The EVA 8901C was originally a prototype formulation of the now commercial A9918. It has finally been removed from exposure after 40,000 hours of time and has only just begun to show signs of degradation. Although the specimens became faintly yellow, all other properties appeared to be intact except for

the surface, which is now badly fractured. The specimen is still easily flexible. The test results show that tensile strength and elongation at break have decreased slightly and that the gel content is still 63%. The change in properties is not considered to be deleterious to the function of this compound as a solar module pottant. However, its high temperature creep resistance should be re-evaluated to determine if an acceptable level has been retained.

Following the obvious successful performance of this prototype compound, a full set of specimens of the commercial A9918 formulation was placed under exposure. At the end of the 15,120 hour exposure, the test results showed no change in the physical or optical properties and the compound appeared the same as the control specimens. These are excellent results for a transparent stabilized polyolefin. The base polymer, uncompounded Elvax 150 (duPont), shows significant signs of degradation after only 500 hours of RS/4 and loses most of its tensile strength and surface hardness.

The EVA formulation 14747 is compounded with the co-reactive UV stabilizer from American Cyanamid designated UV-2098. This compound has been found to react with the EVA formulation during the cure process to become 89% chemically attached and consequently permanently bound. The purpose of this formulation is to prevent loss of the stabilizer from either evaporation or rainwater extraction. No change in properties is found at the 12,000 hour point.

PU-Z-2591 is an aliphatic urethane compound produced by Development Associates, Inc., North Kingstown, Rhode Island (Table 28). This formulation contains a proprietary stabilizer system and prototypes of this formulation are claimed to have endured over six years of unprotected outdoor exposure with no loss of properties. Test specimens have so far endured 14,000 hours of exposure with virtually no change in properties. The slight increase in tensile strength with time is probably due to residual curing reactions that slowly continue to postcure the compound. At the 14,000 hour mark the formation of a faint yellow color was noticed; however, the integrated transmission remains high at approximately 90%. This is excellent performance for a urethane compound, judging from previous testing of urethane compounds.

The last two materials reported are intended for use as white protective back cover films. These films perform the function of providing a reflective back surface for superstrate type modules in order to dissipate heat and provide additional environmental protection. Both these materials began to show sharp decreased in physical properties at the 10,000 hour point and have decayed to about 8% of their original tensile strength at the 15,000 hour mark. These materials have been tested as free standing films directly exposed to ultraviolet light in order to examine their inherent stability. In actuality, they are used on the underside of the module away from direct UV exposure which should extend their service life considerably.

C. RS/4 85°C Exposure

The low temperature (50°C) RS/4 exposures frequently take as long as two years to cause degradation, even in marginally stable materials. Due to the long period of time required to obtain test results, the severity of the condition was increased by raising the temperature to 85°C. This is also a good temperature of choice because rooftop mounted modules may operate at temperatures as high as this. The relative humidity in this condition is also held at approximately 15% with the use of a salt bath in order to simulate a constant level of atmospheric humidity. Tables 31 through 36 give the results for a variety of candidate encapsulants and test materials that have either completed or are currently under exposure at this condition. The results are tabulated as follows:

<u>RS/4 - 85°C</u>			
<u>Table No.</u>	<u>Material</u>	<u>Performance</u>	<u>Exposure Hours</u>
31	EVA A9918	No change	4,000
32	Elvax 16724	This is Elvax 150 cured with Lupersol-101, behind glass. Specimens are pale yellow and flowed/depolymerized.	1,000
33	EVA 16718B	This is EVA with TBEC and UV-2098, but <u>without</u> the Tinuvin <sup>a</sup> 770 stabilizer. Terminated with low gel content, flow, loss of tensile and high surface tack.	1,000
34	EMA 15257C	EMA fully compounded, TBEC. No change.	4,000
35	PU Z-2591	Noticeable coloration, other properties OK.	5,000
36	BA 13870	Some decrease in physical properties, definite decrease in UV cutoff wavelength.	5,000

This test condition is still not as severe as expected and many of the encapsulants are surviving very well. The standard commercially available candidate potant compounds, EVA A9918, EMA 15257C, Polyurethane Z-2591 and Butyl Acrylate 13870, all have shown remarkable stability under this severe condition. No significant changes in properties are found for any of these pottants except for some coloration in the urethane and definite loss of UV absorbing additive in the butyl acrylate.

The dependancy of performance on stabilizers is clearly obvious in observing the rapid degradation of unstabilized compounds. In these cases, the degradation was too severe to permit testing. The experiment with EVA 16178B demonstrates the need for hindered-amine type stabilizers (HALS)<sup>a</sup> and indicates that UV screening alone is not enough to protect the resin. Specimens without the HALS stabilizer wer ound to depolymerize rapidly, lose tensile strength, lose gel content and flow under temperature.

a. The Hindered Amine Light Stabilizers are a relatively new class of extremely effective stabilizers. Tinuvin-770 (Ciba-Geigy) is the most widely used compo ss.

D. CER (Controlled Environment Reactors)

The controlled environment reactor (CER) is a device designed and constructed at JPL<sup>a</sup> and subsequently provided to Springborn Laboratories. It consists of a circular test chamber utilizing a filtered medium pressure mercury arc lamp, optional heaters and a water spray nozzle. The chamber permits the acceleration of solar ultraviolet up to 30 suns in intensity over a temperature range, at the adsorbing surface, of 30°C to 60°C. It is operated at a 50°C specimen temperature with twenty-two hours of "on" time and 2 hours of distilled water spray in the dark.

CER results for EVA A3918 and EMA 15257 are given in Tables 37 and 38, respectively. This condition resulted in degradation of the EVA specimens in 4,000 hours, however no significant changes in the physical properties were noticed through the 3,000 hour pull point. One trend that is observed throughout the exposure period is the continual decline of the UV cutoff wavelength that indicates extractive loss of the UV screener. At the 4,000 hour point, the UV cutoff is 298 nm, which indicates almost complete loss of stabilizer and the gel content has also dropped to 4.4%, indicating de-polymerization. These results suggest that the degradation of the resin is preceded by loss of UV screener which results in destabilization. It will be interesting to see the results of exposure on EVA compounds containing co-reacted UV-2098 stabilizer to determine if there is an improvement in performance.

The EMA out performed the EVA in this test. No de-polymerization was observed and the gel content remained high at 82%. Some coloration was recorded and EMA showed the tendency to increase the UV cutoff wavelength, as has been noticed in other types of exposure. Specimens of EMA will continue to be exposed until some form of failure is noticed.

---

a. E. Laue, A. Gupta, "Reactor for Simulation and Acceleration of Solar Ultraviolet Damage" JPL Document 5101-135, September 21, 1979.

E. Outdoor Photothermal Aging Devices (OPT)

These are devices recently constructed at Springborn Laboratories that constitute a new approach to accelerated weathering. The predominant cause of outdoor deterioration is photothermal aging; the combination of heat and ultraviolet light. In all the laboratory techniques devised to date, it is mainly the light that is increased (photoacceleration) through the use of arcs and discharge lamps. In the OPT reactors, natural sunlight is used as the light source and the specimen temperature is increased. The OPT reactors consist of heated aluminum blocks surfaced with stainless steel and mounting hardware to hold the test specimens flush with the surface. The reactors are tilted at  $45^{\circ}\text{C}$  South and the device turns on at sunrise and off at sunset. Three temperatures have initially been selected:  $70^{\circ}\text{C}$ ,  $90^{\circ}\text{C}$ ,  $110^{\circ}\text{C}$ . This approach eliminates the difficulties associated with the irregular spectrum of artificial light sources, exposes the specimens to other environmental conditions such as rain and pollution, and additionally incorporates a dark cycle. The only acceleration, therefore, is in the temperature, all other environmental conditions being present in their natural occurrence and intensity.

The outdoor photothermal aging racks are operating very well and the temperature control at the surface is excellent. Of all the accelerated aging methods explored at Springborn Laboratories this one results in degradation of candidate materials in the shortest times yet observed. At the 2,000 hour exposure point all specimens of all candidate encapsulation materials have failed at the  $105^{\circ}\text{C}$  temperature, and at  $90^{\circ}\text{C}$  a number of materials have been terminated. At the  $70^{\circ}\text{C}$  condition only one failure has been observed. The end of life for specimens on the OPTs is different than for failures under exposure to the RS/4 conditions, CERs or thermal aging. There is usually some decrease in the gel content and the formation of yellow coloration, however the polymers lose their physical properties by becoming "cheesy" and losing tensile strength, elongation and modulus. At termination, the resins usually have to be scraped off the surface of the OPT and no mechanical properties can be measured. This may be the case even when the gel content is still high. This effect is sometimes observed in polymers in which there are simultaneous chain scission and crosslinking reactions occurring. The effect is that the gel content remains high from crosslinking reactions but the

physical properties resulting from high molecular weight chains is lost. It is not known yet if this is the case with the OPT specimens. Data for the OPT specimens is included in Tables 39 through 46, and is incomplete in some areas, however the blanks will be filled in as results are received from the physical testing laboratory. Useful information developed so far on terminated OPT specimens is given briefly as follows:

Table No.	Material	Performance	Temperature (°C)	Time Hours
- -	EVA 16718B (TBEC, UV2098, <u>no</u> Tinuvin- 770)	Degraded, "cheesy"	70	2,000
39	EVA A9918	Degraded, "cheesy"	90	2,000
- -	EVA 16718A (TBEC, UV2098, Tinuvin-770)	Degraded, "cheesy"	90	1,000
40	EVA 16718B ( <u>no</u> Tinuvin-770)	Degraded	90	1,000
41	EMA 15257	Yellow, "cheesy"	90	2,000
42	PU Z-2591	Very dark color, very sticky, but OK mechan- ical properties. Can- not be handled.	90	2,000
43	EVA A9918	"Cheesy" with some flow, very tacky.	105	2,000
46	EVA 16718B (No Tinuvin-770)	"Cheesy" with flow, no color, cannot be tested, tacky.	105	1,000
45	EMA 15257	Yellow color, "cheesy"	105	2,000
44	PU Z-2591	Dark color, very tacky, cannot be tested.	105	2,000

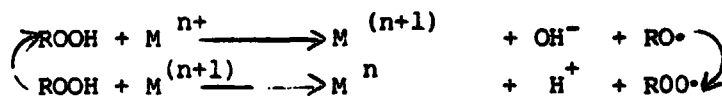
Under this test, the EVA formulation A9918 appears to out perform the new EVA formulation 16718A, which contains TBEC, Tinuvin-770 and co-reacted UV-2098. None of the OPT specimens appear to be losing UV screener and the cutoff wavelengths are unchanged.

The early failure of formulations without the Tinuvin-770 stabilizer again point out the importance of HALS stabilizers on the successful protection of polyolefins.

#### F. Metal Catalyzed Degradation

Copper, and other metals, having two or more stable oxidation stages, are well known for having a "pro-oxidant" activity in polyolefins and result in rapid acceleration of normally slow oxidation rates. This effect is of particular concern in the wire and cable industry where olefin resins are molded over copper conductors and a whole class of polymer additives known as "metal deactivators" have been developed in order to inhibit this effect. Copper is particularly active in terms of catalyzing the type of degradation.

The presence of multivalent metals in polymers is believed to induce or accelerate auto-oxidation in polymers by forming unstable coordination complexes with polymer hydroperoxides. These hydroperoxides then react with the metal ion via an oxidation-reduction mechanism to give free radicals which subsequently initiate the degradation process. The catalytic effect comes from the fact that the metal ion results in the production of free radicals from both high or low oxidation states and therefore "recycles" as shown:



Very small amounts of soluble copper ions in the polymer may have a dramatic effect on the oxidation rate. Metal deactivators are usually "chelating" compounds that are thought to operate by two modes; firstly, complexing the copper ion in the polymer and rendering it chemically inactive, and secondly,

by forming a "passivation" layer on the surface of the exposed metal. Although some of these compounds appear to work quite well, it is generally acknowledged that the polymer that is not exposed to catalytic metals is still more stable than the polymer that is exposed to the metal and has a deactivating additive.

The pottant used in encapsulating PV modules will come in direct contact with metallic conductors on the front and back sides of the cell. Consequently, the possibility of chemical reaction, especially at high temperatures, exists.

Due to the use of metals (and possible use of copper) as exposed conductors in PV modules, a series of experiments were performed to assess the seriousness of this condition. In the thermal aging program, metal "corrosion" specimens were included in all conditions ( $60^{\circ}$ ,  $85^{\circ}$ ,  $105^{\circ}$  and  $130^{\circ}\text{C}$ ) and consisted of strips of copper, aluminum, and 60/40 lead/tin solder. Even at the highest temperature and at the longest times no adverse effects were noticed with the aluminum or solder. The copper proved to be very catalytic, however, and resulted in discoloration of the host resin and rapid deterioration of physical properties. The pottants, EVA, EMA and polyurethane were all completely degraded by the presence of copper at  $105^{\circ}\text{C}$  in approximately 400 hours. Due to this observation, a series of experiments on metal deactivation were conducted to determine if this effect could be inhibited through the use of deactivator compounds or possibly by silane passivation of the copper surface.

Test specimens were prepared by molding the candidate resin formulation over a copper screen to yield a coupon that could be monitored by spectroscopy. The earliest quantifiable sign of polymer degradation (non-destructive) is yellowing, which is most easily monitored by measuring the percent transmission at 450 nm. The use of copper screen permits the resin to come into intimate contact with the resin and still be monitored by transmission measurements. Three resins were chosen for study: EVA, EMA and PVB (Saflex PT-10). With the exception of PVB, which was used in its unmodified form, all resins were crosslinked with 1.5 phr of Lupersol - TBEC and 0.2 phr of a metal deactivator (except the control). Two metal deactivators were evaluated, MD-1024 (Ciba Geigy) and Cyanox 2379 (American Cyanamid). The Cyanox 2379 is not a commercial product, however it was evaluated following a

literature search that indicated it to be the most effective deactivator for polypropylene yet discovered. The test specimens were measured for color change and visible changes after thermal aging at 105°C in both air and nitrogen. The results are shown as follows:

<u>Polymer</u>	<u>Deactivation</u>	<u>Lifetime, hours</u>
EVA (air)	None	650
(crosslinked w/1.5 phr TBEC)	+ Silane	840
	Cyx 2379	990
	MD1024	1150
	MD1024 + Silane	1024
	Cyx 2379 + Silane	1320
EMA	None	840
(crosslinked w/1.5 phr TBEC)	+ Silane	990
	Cyz 2379	1930
	Cyx 2379 + Silane	1930
	MD 1024	3700
	MD 1024 + Silane	3700
(EMA results essentially the same in nitrogen).		
EVA (nitrogen)	Cyx 2379 + Silane (15299-3B-N <sub>2</sub> )	> 8500 <sup>a</sup> .
PVB	None + Silane	350

a. Will be left in the aging conditions until failure is observed.

As may be seen, silane treatment of the copper appears to provide a chemical barrier that aids in the corrosion decoupling of the polymer and the metal. Additionally, silane treatment of the copper appears to improve the effectiveness of the metal deactivator synergistically and further extend the lifetime. The least metal catalyzed oxidation was found for those specimens including both metal deactivator and silane treated copper.

All of the specimens initially included in this test have failed, except for one, 15299-3B, which is cured EVA compounded with 0.2 phr of Cyanox 2379 metal deactivator and the copper screen treated with Z-6030 silane. The specimen has been aging in a nitrogen atmosphere for 8,500 hours with some yellowing of the polymer and no signs of corrosion in the vicinity of the copper. This is remarkable in comparison to the lifetime of the other specimens.

PVB reacted severely with copper and became very yellow within 350 hours. The resin also flowed for awhile and then stopped, probably due to the loss of plasticizer. At the 1,000 hour mark the specimens retained around 2% of the original %T-400 nm and throughout the test the silane treated copper specimens appeared to degrade slightly faster than the untreated specimens.

When compared to plain thermal aging without the presence of copper, it may be concluded that deactivators may help retard the pro-oxidant effect. However, the absence of exposed copper will be required for long lifetimes of polymers serving as pottants at rooftop array operation temperatures.

Due to the possible acceleration of thermal oxidation effects by multivalent metals, other metals should be screened for activity. To date, no adverse reaction have been found with the high temperature exposure of candidate pottants to aluminum, lead-tin solder (60/40), silver, nickel or titanium.

Some general conclusions may be drawn from the results of the accelerated aging experiments to date. These are:

1. The severity of the aging conditions examined to date is:  
 RS/4 (least) < RS/4-85°C < Thermal aging, 105°C <  
 Controlled Environment Reactors (CER) < Outdoor Photothermal  
 reactors, << Copper catalyzed degradation, 105° (worst)

2. The first property to change is most frequently color (yellowing).
3. The properties least affected are mechanical and dielectric.
4. In terms of modeling, the degradation curves are predominantly "induction period" type and very few resemble first-order behavior.
5. Thermal aging: candidate pottant compounds EVA, EMA and Butyl acrylate have been found to be surprisingly stable, enduring 1,000 hours at 130°C with little change in useful properties, although there is some evidence indicating the volatile loss of UV absorber. The aliphatic polyurethane pottant is the most thermally degradable candidate examined and terminates within 100 hours at 130°C. At 105°C, this material still shows signs of degradation and it becomes darkly colored. This candidate should not be used in modules applications where high temperatures are anticipated.
6. RS/4 Exposure: This technique is useful for assessing the relative performance of marginally stable materials, however very light-stable materials require years before the onset of degradation occurs. All the candidate materials perform very well in this test.
7. RS/4 - 85°C: despite the increase in temperature, the candidate pottants still perform extremely well in this exposure condition, enduring 4,000 hours to date with no significant property changes. Unstabilized EVA and formulations without HALS type stabilizers degraded severely within the first 1,000 hours.
8. HALS stabilizers appear to be essential for the long life of EVA formulations.
9. Controlled Environment Reactors (CER): this UV light exposure condition is more severe than the preceding tests. Induction type behavior is observed in EVA and degradation of physical properties is reached in 4,000 hours. There are indications, however, that this may be due to extractive loss of stabilizer.
10. Outdoor Photothermal Reactors (OPT): these devices are very useful as they produce results in a few months instead of a few years. The type of degradation effects with these devices is different then observed with other accelerated aging techniques. All materials degrade under these (90°C and 105°C) conditions.

11. Metal catalyzed degradation is the most severe form of accelerated aging discovered yet. The use of metal deactivators and silane treatment of the metal surface definitely extend the lifetime , however, it is strongly suggested that exposure to metallic copper be avoided. No reactions are observed with aluminum, 60/40 solder nickel, silver or titanium.

#### IV. WATER ABSORPTION

Photovoltaic modules deployed outdoors will obviously be exposed to all the elements of weather, including moisture, rain, snow and other conditions where water absorption by encapsulation materials is a possibility. This absorption of water could be deleterious to module functioning and life expectancy. The absorption or intrusion of water could result in problems such as: delamination, extraction of stabilizers, swelling or change in dimensions, and hydrolysis (chemical decomposition) of the encapsulant itself. Due to these concerns, especially with respect to pollutants, an experiment in water absorption was conducted to determine the effects of water immersion (100% relative humidity) at a wide range of temperatures.

Specimens of the four pollutants, EVA, EMA, Polyurethane and Butyl Acrylate, were carefully prepared to have a low surface area to volume ratio and were also degassed under vacuum to constant weight. The polymers incorporated all the compounding ingredients required for adequate curing, however, all the water extractable stabilizers were left out. Specimens of the candidate encapsulants were immersed in distilled water in sealed jars and subsequently equilibrated at temperatures of 20°C, 50°C, 60°C, 70°C, 80°C and 90°C. Each specimen is removed for weighing at weekly intervals in order to examine the equilibrium water concentration and activation energy of hydrolysis.

Data for twenty three weeks of water absorption are given in graphical form on Figures 1 through 4 to observe the trends in weight gain, if any. For EVA, the amount of water absorbed increases with an increase in temperature. At 20°C, the polymer equilibrates at approximately 0.25 weight percent absorbed water with little fluctuation. For increasing temperatures, the performance is much the same, although the amount of water gained increases and the fluctuations in measured weight are a bit more pronounced. At 80°C the absorbed water equilibrates at a mean of 0.5 weight percent and remains fairly constant. The data for 90°C is the only curve that appears to show a trend towards increasing absorption with time. This specimen starts with a 0.5% gain in weight which steadily increases to 0.8% over the twenty-three month exposure period.

This is thought to be due to slow hydrolysis of the resin under these conditions which results in the conversion of the vinyl acetate group to the vinyl alcohol which is water soluble. Specimens of EVA begin to be noticeably hazy at 80°C and almost white in appearance at 90°C.

The EMA showed much less temperature dependence on water absorption than the EVA, with most values in the 20°C to 80°C range equilibrating in the 0.15 to 0.25 weight percent range. The 90°C temperature shows steadily increasing values from 0.19% to 0.32% over the exposure period. This could possibly be due to hydrolysis of the methyl ester group that would be converted to the more hygroscopic carboxylic acid. EMA begins to show visible signs of haze at the 60°C immersion that increases with increasing temperature.

The Z-2591 polyurethane shows the most extreme behavior of the four potantants under investigation. At all temperatures, the weight gain curves show a steady decrease in the amount of water gained after an initial absorption of about 3%. For the immersions between 20°C and 80°C the trend is gradual and may possibly be due to extraction to stabilizers as the resin used is a commercial grade known to contain low molecular weight compounds. If so, these curves should begin to level off to fixed values after the stabilizers have been fully extracted. The curve for the 90°C condition is distinctly different from the others. The data 3.07% increase in weight after the first week of immersion and steadily loses weight until, in the twenty-third week, a loss of 0.44 % over the initial weight was recorded. This is most likely due to hydrolytic scission of the urethane polymer which is also indicated by noticeable softening of the resin and an increase in the surface tack. Specimens under these conditions become somewhat hazy, appear darker yellow in color and very sticky.

Poly(butyl acrylate) is the last resin under test. At 20°C the water absorption is in the order of 0.25%, which increases to about 0.75% at 90°C. The data points for this material are a bit more scattered for this resin than for

the other materials so trends are not as easily observed, however, weight loss may be occurring in the specimens at higher temperatures.

In conclusion, the data gathered so far indicates that the EVA and EMA candidate pollutants equilibrate at weight percent water absorptions that increase with increasing temperature up to 80°C. At the 90°C immersion there is evidence of hydrolysis in the two polymers, the EVA being noticeably more affected than the EMA. The aliphatic urethane is very much more sensitive to hydrolysis than any of the other resins tested. Even at temperatures as low as 20°C there are signs of chemical degradation. At the 90°C condition, the hydrolytic attack on this compound is very rapid and the resin appears to be slowly dissolving into the water phase.

## V. PRIMERS AND ADHESIVES

Adhesives, primers, or some other mechanism are necessary for the high reliability bonding of the assembly components to one another in order to insure the structural integrity and long life performance of the module. The adhesion between the pottant and other components, i.e., substrate, superstrate and outer cover, was investigated in the past year and some encouraging results were obtained with the use of primers.

A primer operates by creating a reactive chemical interface between two components, whereas an adhesive is a discreet compound that constitutes a separate phase to which the two other components may bond. Primers have been emphasized in the bonding studies due to a number of advantages they present in use. Primers are (a) used in exceedingly small quantities, (b) are cost effective, are (c) easily applied to surfaces, (d) function by the formation of high strength chemical bonds, and (e) may possibly be combined into the pottant systems to eliminate the priming step.

Tables 47 through 52 show the results of adhesion bond strength evaluations of materials and primers investigated to date. The test specimens were prepared in a manner similar to that which would be encountered in a actual module fabrication. All substrate/superstrate specimens were evaluated by ASTM method D-903 for the peel or stripping strength of laminates, in which the polymer layer is pulled back off the substrate at a 180 degree angle. For flexible specimens, such as polymer bonded outer cover materials, ASTM method D-1867 ("T" - Peel) was employed. All values are reported as pounds of stress per inch of width of bond line. Specimens showing high control values were further tested after water immersion for two weeks and exposure to boiling water for periods of two hours. These simple tests give a good indication of bond durability.

The tables record the measured stress values at break, and are shown as separate tables for each of the pottants; EVA, EMA, polyurethane and butyl acrylate. From the large number of experiments listed in these tables a certain number of successful formulations and material combinations may be identified. For the purpose of clarity, these results are now given as follows:

<u>Pottant To:</u>	<u>Primer</u>	<u>Control</u>	<u>Adhesion, lbs/in Width</u>	
			<u>2 Hours Boiling Water</u>	<u>2 Weeks Water Immersion</u>
EVA A9918:				
Sunadex	11861	32	28	30
Mild Steel	11861	> 30	> 30	> 30
Tedlar	68040	> 30	> 30	> 30
200BS30WH				
Tedlar	107D	> 30	> 13	> 30
100BG3OUT				
Scotchpar 20CPW	14719	35.7	31.3	21.3
(Polyester)				
Copper	16180	32.5	43.4	37.6
Kyrar 450	68040	5.7	6.1	4.1
Solder	16160	9.8	9.0	7.7
Aluminum	16180	6.5	3.7	3.2
Plexiglass	68040	40.2	42.4	44.1

As may be seen, many very good primer material combinations have been identified for the bonding of commercial EVA A9918 to a number of other candidate module encapsulation candidates, including low-iron glass, metals, back and outer cover films. Due to the desire for more rapid cures, lower lamination temperatures and faster throughputs, new formulations of EVA containing TBEC peroxide as a curing agent, are being developed.

ORIGINAL PAGE 18  
OF POOR QUALITY

EVA that is TBEC modified, Table 49, is obviously different in chemistry. With the use of All861 primer, EVA 9918 bonds to mild steel extremely well to give bond strengths in excess of 40 lbs/inch for all three conditions. The TBEC modified formulation with All861 gives a control value of only 8 lbs/inch and values of 5.2 and 2.3 lbs per inch of width for the water immersion and two hour water boil exposures, respectively. Bond strengths to glass were comparable. Due to the increasing interest in the fast-cure TBEC formulation, more work in these areas of adhesion is required. Another consideration is that manufacturers may choose to use this pottant at lower cure temperatures, consequently the bond strengths resulting from lower temperature processing must be investigated. This work has started, however, no test results are available yet. All the adhesion work to date with EVA and EMA is done on specimens bonded at 150°C for 20 minutes. A few fairly good combinations are shown as follows:

good combinations are shown as follows:			Adhesion, lbs/ in Width	
<u>Pottant To:</u>	<u>Primer</u>	<u>Control</u>	<u>2 Hours Boiling Water</u>	<u>2 Weeks Water Immersion</u>
EVA 15295 (TBEC Cure):				
Sunadex	11861	51.3	32.9	33.3
Mild Steel	11861	8.0	5.2	2.3
Aluminum	16180	5.6	3.0	3.0

Despite the similarities in cure chemistry, EMA is much more difficult to bond than the EVA. Primer formulations effective with EVA are sometimes only marginally useful with the EMA. To date, the only primer that has given good results with this pottant is All861, which gave excellent strength to Sunadex glass and good performance with mild steel.

EMA (Table 50) is more easily bonded in its TBEC modified formulation than the Lupersol 101 cured compound (now discontinued). Although the bond strength to Sunadex glass is excellent, the bond strengths to most metals and organic outer cover films are marginal. So far, the only possibly good combinations are, Sunadex glass/All861, Tedlar 100BG30UT/68040, and Nickel/All861. More experimentation is required to expand the range of primer and material combinations suitable for use with this pottant.

To date, the only successful material combinations found are:

Pottant To:	Primer	Control	Adhesion, lbs/in Width	
			2 Hours Boiling Water	2 Weeks Water Immersion
EMA 15257:				
Sunadex	11861	Broke	64	45
Tedlar 100BG30UT	68040	- - - - Film Tore	- - - -	
Scotchpar	14719	5.0	6.8	1.5

Due to the slightly lower interest in the casting syrup pottants, less emphasis was placed on adhesion experiments with the aliphatic polyurethane and the polybutyl acrylate candidate pottants. In addition, both these polymers have inherently low tensile strengths which naturally result in low peel strengths. For materials such as these, it is the bond durability that is of most importance. With the exception of the urethane to Sunadex glass adhesion, all the other peel strengths were of low value, as shown:

			<u>Adhesion, lbs/in Width</u>	
<u>Pottant To:</u>	<u>Primer</u>	<u>Control</u>	<u>2 Hours Boiling Water</u>	<u>2 Weeks Water Immersion</u>
PU Z-2591:				
Sunadex	Z6020	31	37	45
Korad 63000 (Back Cover)	Z6020	4.1	2.5	2.7
BA 13870:				
Tedlar (100BG30UT)	Z6032W	2.3	2.3	2.3

Primers are applied to the surfaces of interest from dilute solutions and usually in extremely small quantities. For this reason they are very economical in terms of raw materials cost. The cost component for the use of primers results from the application step. Coating machinery must be set up to convey the components, apply a thin layer of liquid primer solution, permit it to dry, ventilate the vapors, and finally deliver the components to the laminator. Due to the obvious expense of this step, Springborn Laboratories has investigated the incorporation of priming compounds directly into the pottant formulation to yield "self-priming" compositions. Due to the water sensitive nature of most (silane type) primers, concern was raised about humidity exposure and shelf-life or storage problems with such formulations.

Table 53 gives the results of bonding EVA 9918 to Sunadex glass after the incorporation of different levels of Z-6030 silane into the resin. Adhesion to the glass was measured in the usual control, 350 hour water immersion, and two hour water immersion scheme. Measurements were also taken after storing the resin under "typical storage conditions" for two months. Three levels of incorporated primer were also tried, 0.25, 0.1 and 0.05 phr. The results were extremely encouraging and the incorporated silane was found to be effective down to the lowest level of 0.05 phr. Additionally, the two month storage time did not significantly reduce either bond strength or retention after the water exposure conditions (although the values were a bit lower). In general, the results were excellent and are given in the following chart:

<u>Potant/Primer</u>	<u>Level (phr)</u>	<u>Bond Strength, lbs/in</u>	
		<u>Control *</u>	<u>Two Months Storage*</u>
EVA A9918	0.25	42	44
Z-6030	0.05	29	24
EVA 15295/	0.25	31	32
Z-6030	0.05	10.9	9.5
EMA 15257/	0.25	57.4	58
Z-6030	0.05	49.0	39.3

\* Bonds also stable to water immersion and boiling water

Although the self-priming formulations to glass work very well, perhaps what is more urgently needed is an internal priming system that bonds the pottant to the cell strings - - and thereby avoiding a very expensive priming step. The glass superstrate may be externally primed much more easily and less expensively. This approach will be considered when more effective formulations for bonding the pottant to metals and cells have been discovered.

## VI. SOILING EXPERIMENTS

The performance of photovoltaic modules is adversely affected by surface soiling, and generally, the loss of performance increases with the quantity of soil retained on their surfaces. To minimize performance losses caused by soiling, photovoltaic modules not only should be deployed in low-soiling geographical areas, but also should have surfaces or surfacing materials with low affinity for soil retention, maximum susceptibility to natural removal by winds, rain, and snow; and should be readily cleanable by simple and inexpensive maintenance cleaning techniques.

The action of soiling is considered to include accumulation, natural removal by wind, rain, and snow; and activation of mechanisms that result in surface soiling that resists natural removal, thus requiring maintenance methods.

The theoretical aspects of soiling have been addressed recently in documents by the Jet Propulsion Laboratory.<sup>a., b.</sup> The basic findings of these studies show that the rate of soil accumulation in the same geographical area is material independent and that rainfall functions as a natural cleaning agent. The effectiveness of the cleaning effect of the rain is material dependent, however.

Based on the postulated mechanisms for soil retention on surfaces, certain characteristics of low-soiling surfaces may be assumed. These are: (a) hard, (b) smooth, (c) low in surface energy, (d) chemically clean of water soluble salts, and (e) chemically clean of sticky materials. It is possible that cost effective coatings having these required properties may exist and be applied to solar module surfaces and result in low maintenance costs and preserve the effective generation of power from these devices.

- 
- a. Cuddihy, E. F., "Encapsulation Materials Status to December 1979" LSA Project Task Report 5101-144, Jet Propulsion Laboratory, Pasadena, CA January 15, 1980.
  - b. Hoffman, A. R., and Maag, C. R., "Airborne Particulate Soiling of Terrestrial Photovoltaic Modules and Cover Materials", Proceedings of the Institute of Environmental Sciences, May 11-14, 1980; Philadelphia, PA.

The candidate materials for the outer surface of solar modules currently consists of low-iron glass, Tedlar fluorocarbon film (DuPont) and a biaxially oriented acrylic film, Acrylar (3M Corporation; product X-22417). These materials are all relatively hard, smooth and free of water soluble residues, consequently experiments were conducted to determine if an improvement in soiling resistance could be obtained by the application of low surface energy treatments.

A survey of coating materials showed that very few commercial materials exist that could be useful for this purpose and that experimental compounds may also have to be synthesized.

A series of antimigration coatings designated FC-721 and FC-723 are available from 3M Corporation and are claimed to have extremely low surface energies; in the order of 11-12 dynes/cm. These compounds are based on a fluorinated acrylic polymer and are so effective in reducing surface tension that silicone oil beads up on the surface of glass treated with this material. The difficulty with these coatings is that they are very easily removed and have virtually no permanence on the surfaces attempted. They were, therefore, not used in the experimental soiling work and more durable candidates were selected.

A total of seven coatings/treatments were selected for soiling resistance evaluations, as follows:

1. L-1668. an experimental fluorochemical silane produced by 3M Corporation that is used to impart water and oil repellency to glass surfaces. This material is not yet commercial.
2. L-1668 following treatment of the surface with ozone activation (for the organic films only).
3. Dow Corning E-3820-103B, an experimental treatment consisting of perfluorodecanoic acid coupled to a silane (Z-6020). This compound is not commercially available.

4. The E-3820-103B following surface treatment with ozone to create active sites on the organic polymer films.
5. Glass resin 650, produced by Owens-Illinois (commercially available).
6. SHC-1000, a silicone based hardcoat resin produced by General Electric (commercially available).
7. WL-81 acrylic resin produced by Rohm and Haas (commercially available).

Ozone treatments are not used with the glass because no surface activation occurs in this case.

These coatings/treatments were applied to each of the three candidate outer surfaces using the recommended application technique. The organic film materials, Tedlar and Acrylar, were supported by a piece of glass on the underside, and attached with a colorless and ultraviolet stable pressure sensitive adhesive.<sup>a</sup> The completed test coupons were then mounted in outdoor racks on the roof of Springborn Laboratories' facilities in Enfield, Connecticut. Evaluation was performed monthly and a record of rainfall was kept in order to correlate soiling effects with precipitation.

The degree of soiling on the completed specimens was measured by power transmission using a specially designed standard cell device. This instrument measures the drop in short circuit current,  $I_{sc}$ , with the use of a laboratory grade volt-ohm meter. This method was found to be better than spectroscopic measurement, due to difficulties in mounting the test specimens at the spectrometer port. Additionally, the use of a silicon cell as a detector gives a more meaningful reading due to the response to scattered light and the direct measurement of the variation in cell power.

a. Royal M6112 acrylic pressure sensitive adhesive - Uniroyal Chemical Company.

#### VI-4

The results of 24 months of outdoor exposure are given in Tables 55 through 57 , and Figures 5 through 7 . The tables give the values for the percent variation in short circuit current for Sunadex glass, Tedlar film and Acrylar film, for each month and each coating. In the figures, the values for control and the two best performing treatments are graphed for clarity.

After the first twelve month exposure period, the overall trends of the soiling specimens were evaluated and a decision was made to continue with the treatments that showed promise and to drop the coatings that did not perform as well as the control. The treatments that were discontinued at this time were the Ol-650 glass resin, the SHC-1000 silicone hard coat and the WL-81 acrylic latex. These materials gave either no improvement in performance or caused the specimen to accumulate more soil than the untreated surface.

The data for Sunadex low-iron glass is given in Table 55 and Figure 5 . Sunadex glass, and the treatments applied to it, gave specimens with the best overall inherent soil resistance. The control and most of the coated specimens followed the same pattern of rising and falling simultaneously throughout the exposure period and the rainy months showed a dramatic decrease in power in all cases. A constant differential was found between the control measurements and the two most effective coatings, E-3820 and L-1668, which were consistently in the order of one to two percent better than the untreated control. This has been the case throughout the exposure period except for the twenty-fourth month, in which the control gave slightly better performance. The decline in soil repellancy in the last two months may indicate that the useful life of these treatments may be over, however, it will take a few more months of data with additional rainfall to know for sure if this is true. In all, the treated specimens have shown a significant improvement in the transmission of usable power and have "self-cleaned" effectively during periods of sufficient rain. The E-3280 treatment has been found to be somewhat better than the L-1668, and the enhancement of power from a module with this coating is estimated to be about 1% over a two year period.

Data for the second candidate outer surface, Tedlar (100BG30UT) fluorocarbon film is given in Table 56 and Figure 6 . The overall performance and inherent soiling resistance of this material is much worse than for the Sunadex glass. Untreated control specimens degraded steadily in power throughout to a maximum loss of 8.8% in the tenth month, recovering to about 5% in the subsequent months. All the coatings applied to Tedlar improved its resistance to soil accumulation, however, the fluorosilane treatments were conspicuously better than the other.

Of all the treatments used with Tedlar 100BG30OUT, only one appears to retain its usefulness at the 24 month point. Again, E-3820 is found to be the most effective coating and shows significant improvement over the control values. Treatments with E-3820 result in  $I_{SC}$  measurements that run consistently 3-5% better than the control or other treatments. The usefulness of this coating on Tedlar is clearly shown in the Figure ( 6 ) and the estimated improvement in produced power over a two year period of time is about 3.8%.

Data for the last candidate film, Acrylar X-22417, is given in Table 57 and Figure 7.

The Acrylar acrylic film formulations soiled much more severely than the Sunadex glass and Tedlar specimens. All the specimens steadily lost power throughout the exposure period, however, almost all of the treatments had a beneficial effect. The uncoated control specimens soiled very badly and at one point (10th month) dropped to a low -10.8% power loss. Following this point, the control fluctuated at about 7-8% decrease in  $I_{SC}$ , while the treated specimens varied widely in value.

In the first year of exposure, the L-1168 treatment was marginally better than the Ozone/E-3820 fluorosilane, both running 2% to 3% ahead of the control. In the second year, however, the effectiveness of the L-1668 appears to decline and the Ozone/E-3820 performs conspicuously better, returning to 0% loss in

in the twenty-first month, following heavy rainfall. This treatment was found to run several percent better than the other surface chemistries and about 6% better than the control. Over a two year period of time, the estimated improvement in short circuit current is estimated to be about 3.9%.

Observations of the data trends in soiling show that the low points, in the tenth and twentieth months, correspond to periods of little rainfall. These are the winter months in Enfield where there is almost no rain and the precipitation occurs as snow, which is not thought to have much of a cleaning action on the specimen surface. All the specimens begin to regain their transmission and  $I_{sc}$  values as the Spring rains occur in the months of April through June. The rainfall data, which correlates well with the fluctuations of soiling data, is given in Figure 8.

In summary, low surface energy treatments, based on fluorosilane chemistry, appear to be effective in retarding the accumulation of soil on candidate outer surfaces of interest in module construction. The most successful treatments identified to date are: for Sunadex and Tedlar, E-3820, for Acrylar, ozone pretreatment followed by E-3820. This surface coating is based on expensive fluorochemicals, however, it should prove to be cost-effective due to the extremely small amount that is applied to the surface. This coating appears to be effective where there are weather conditions that result in "natural cleaning" of the surface, and it seems that a certain amount of rain is required to keep the light transmission high.

VII. CORROSION PROTECTION

Springborn Laboratories, Inc. has conducted extensive surveys into materials that may be useful as cost-effective substrates for photovoltaic modules<sup>a</sup>. The results of these surveys suggest that the load bearing element, either substrate or superstrate, will be the most expensive single component in the encapsulation package. Given the overall encapsulation cost goal of \$14.00/m<sup>2</sup> (1980 dollars), the load bearing element may amount to as much as 50% of the cost, or up to \$7.00/m<sup>2</sup>.

Surveys have identified potential construction materials on the basis of the flexural strength required to meet the load deflection specifications and the cost of the material at the required thickness. The materials identified to date are as follows:

<u>Candidate Material</u>	<u>Estimated Cost</u>	
	<u>\$/ft<sup>2</sup></u>	<u>\$/m<sup>2</sup></u>
Hardboards (Masonite, "Super-Dorlux", Ukiah Standard Hardboard)	0.14	1.52
Strandboard (Potlatch-under development)	0.17	1.80
Glass-Reinforced Concrete (MBA Associates)	0.60	6.50
Mild Steel (28 gauge) (base cost appx. 1¢ per sq. ft. per mil of thickness)	0.25	2.70

Mild steel is the least expensive metallic material found to date and offers the advantage of easily shaped into structures that have integral stiffening ribs incorporated into the manufactures structure. The stiffening ribs may permit the reduction of panel weight and thickness in order to meet the deflection load specifications and additionally result in a cost optimized structure.

---

a. Willis, P. and Baum, B., Investigation of the Test Methods, Material Properties and Processes for Solar Cell Encapsulants, Annual Reports II and III to Jet Propulsion Laboratories, Contract 954527, July 1978 and July 1979.

## VII-2

The difficulty with the use of mild steel is its inherent corrosion sensitivity. Modules deployed outdoors without some protection provided for the steel will probably not last the twenty year period without rust, resulting in delamination of the encapsulated cell strings from the surface and possible mechanical deterioration of the steel structure itself.

The application of protective coatings is the easiest and most obvious way to preventing the corrosion chemistry from occurring. Coatings form a barrier between the metal and its environment and isolate it from the electrolytes that are required for any of the corrosion mechanisms to occur. A good protective coating must resist acids, alkalis, salts, moisture, ultraviolet light and have good adherence to metal surface for which it is intended.

Coatings may be divided into three groups; metallic, inorganic, and organic.

Metallic coatings include metal spraying, cladding, hot-dip coatings and electroplating. The least expensive metallic coatings is hot-dip galvanizing with a cost increment of about 20% over plain cold rolled mild steel. Aluminum clad rolled steel is also available, however it is almost twice as expensive (varies with grade and manufacturer).

Inorganic coating refers basically to porcelainization - a process of applying a glass frit to the surface of the steel and then firing until the glass fuses to the surface. This approach works well in terms of corrosion protection, however it is sensitive to mechanical flexing and is also expensive. The steel sheet that is suitable for porcelain enameling costs about 15% more than mild steel and the enameling process itself adds, perhaps an additional 50% to the overall cost.

Due to the ease of use, the ability to coat complex geometries, and cost benefits, our approach to the corrosion problem has emphasized the use of organic coatings. Several approaches are under consideration. The possibilities include (a) encapsulation of the entire steel substrate with the weatherable pottan: compound, (b) lamination with an occlusive foil (i.e. aluminum foil) and the use of a hot melt adhesive, (c) lamination with organic films, such as pigmented polyester, and (d) combinations of these techniques. The

goal is to systematically identify, assess and cost out candidate coating systems that can meet the twenty year life criterion at the lowest possible cost.

Candidate corrosion protective treatments are being identified at Springborn Laboratories and cost effective materials or combinations of materials are evaluated for their corrosion protection with accelerated methods.

To date, a number of corrosion test specimens have been prepared with a variety of coatings and evaluated for performance in outdoor exposure and indoor heated salt spray (ASTM B-117) tests. These coatings are based on adhesive/film combinations and also some maintenance coatings.

The salt spray condition is conducted in a closed chamber at 35°C with a continual spray of 5% salt solution sprayed on the test specimens. This condition is widely used in the plastics and coatings industries for the assessment of protective coatings, but is recognized as being a severe test. Very often, the lifetime of test specimens is measured in hours. This may be seen in the case of the mild steel control in which extensive corrosion is observed after only 3 hours exposure.

A new series of corrosion specimens were prepared and placed in the standard outdoor weathering racks and also in the ASTM B-117 salt fog chamber at 35°C. All the specimens were prepared using conventional mild steel and a metal/ceramic primer coat known as "Alseal-518", available from Coatings for Industry, Inc., Souderton, PA. This is an aluminum pigmented inorganic water based coating system that is used mainly for coating aircraft engine parts. It may be applied to the mild steel by spraying. This coating is applied at a thickness of approximately 1 mil and an estimated cost of approximately 7¢/ft<sup>2</sup>/mil of dry coat (small lot cost). The dried coating requires proper curing in order to acquire its corrosion resistant property.

One of two conditions may be used; firing at 600°C for 5 minutes, or firing at 260°C followed by glass bead burnishing to remove the "glass" surface and expose the conductive ceramic layer. These two finishes are referred to as "fired" and "bead", respectively. The manufacturer claims that the one mil

11

1

11

1

- ...

- 11

- 1

- 1

- 7

- 7

- 

- 4

- 11

- U

- 

- 3

- 1

- 1

- 1

- 11

- 1

- 7

-

VII-5

Topcoated specimens are performing reasonably well, although some blistering of the coatings in areas other than the scribe mark are occurring after the 2,000 hour exposure point. Heavy rust along the scribe mark with delamination of about 1/4 inch of the coating is typical and no test panel is conspicuously better than any of the others. The underside of the panels are remarkably unchanged. Specimens numbered 4, 5, 7, and 8 are all rated "1" - no noteable change in appearance, a very encouraging result. Apart from a thin line of rust appearing on the scribe mark, no deterioration is observable at all on the specimens exposed in the outdoor racks.

The test panels will continue under exposure until failure occurs.

A P P E N D I X A

TABLES 1 - 60

TABLE I

Status of Candidate Encapsulation Materials  
(Identified in Springborn Labs Program)

1.	Surface materials & modification	Under development (Springborn)
2.	Top Covers (with UV screening property)	
a.	Glass	Available, many commercial sources
b.	Tedlar X00 BG 30 UT	Available (DuPont)
c.	Acrylar Acrylic film (X-2241-6, -7)	Available (3M Corp.)
3.	Pottants	
a.	Ethylene Vinyl Acetate (A9918)	Available (Springborn, Rolland)
b.	Ethylene Methyl Acrylate (13439)	Available (Springborn)
c.	Aliphatic Polyether Urethane (Z-2591)	Available (Development Associates)
d.	Poly Butyl Acrylate (13870)	Available (Springborn)
4.	Electrical and mechanical spacer	
a.	Non-woven glass mats	Available (Crane Co.)
5.	Substrate panels	
a.	Hardboards	Available (Masonite, "Super-Dorlux", Laurel 200, Ukiah Standard Hardboard)
b.	Strandboard	Under development (Potlatch Corp.)
c.	Glass-reinforced concrete	Under development (MB Associates)
d.	Mild steel (including gal- vanized & enameled)	Available, many commercial sources
6.	Back Covers	
a.	Aluminum foils & polymer laminates	Available
b.	Tedlar, Mylar, Korad (polymer films)	Available (DuPont, Excell, 3M)
7.	Gaskets	
a.	EPDM (standard or custom profiles)	Available (Pawling Rubber Co., others)
8.	Sealants	
a.	"Tape" sealants	Available (Tremco; Pecora, 3M)
b.	Gunnable sealants	Available (Tremco, 3M, others)

ORIGINAL PAGE 18  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 2

Exposure Condition: Thermal Aging

Material: EVA

Notebook No: A9918

Atmosphere: Air

Temperature: 80 °C

Description:

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date:						
	Unit No.:						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	1,890	2,890	2,820	3,020	3,120	
	Ult. elongation, %	510%	684%	648%	621%	626%	
	Modulus, psi	890	980	878	922	1,100	
	Swell ratio, %	32.2	18.4	19	18.9	10.9	
	Gel content, %	74%	74.2%	79.1%	69.5%	88.2%	
	Appearance	Colorless Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	355	356	356	353	344	
	Color *	76.0	63.0	72.3	66.9	69.8	
Elect.	Dielect. Stgth., V/mil	900	960	1030	1090	1000	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	61	57.7	56.8	43.3	53.9	
	Copper metal	---	1	1	2	2	
	Aluminum	---	1	1	1	1	
	60/40 Solder	---	1	1	1	1	
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes:

1 = no change      4 = strong color      7 = melted  
 2 = faint color      5 = degraded      8 = broken  
 3 = moderate color      6 = extreme degradation      9 = surface cracks

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No. 6072.1

POLYMER AGING STUDIES

Table 3

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Nitrogen

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	1,890	2,780	2,990	2,670	3,310	
	Ult. elongation, %	510%	696%	655%	592%	595%	
	Modulus, psi	890	940	904	951	1,200	
	Swell ratio, %	32.2	24.4	37.8	12.5	11.3	
	Gel content, %	74%	70.8%	64.1%	76.8%	86.9%	
	Appearance	Colorless Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	355	353	349	348	345	
	Color *	76.0	65.6	71.4	61.7	75.8	
Elect.	Dielect. Stgth., V/mil	900	1100	960	700		
	Leak current, uA	0	0	0	0		
Corrosion *	Copper dust, %T	61	57.7	58.8	51.2	56.1	
	Copper metal	---	1	1	2	3	
	Aluminum	---	1	1	1	1	
	60/40 Solder	---	1	1	1	1	
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 4

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	1,890	2,230	2,410	2,590	3,249	
	Ult. elongation, %	510%	670%	700%	659%	657%	
	Modulus, psi	890	950	1,050	916	1,160	
	Swell ratio, %	32.2	42.9	26.8	25.5	16.5	
	Gel content, %	74%	50.2%	59.2%	66.1%	78.7%	
	Appearance	Colorless Clear	1	1	1	2	
Optical	Total optical, %T						
	UV cutoff, nm	355	350	348	349	340	
	Color *	76.0	68.5	60.7	64.3	78.0	
Elect.	Dielect. Stgth., V/mil	900	1040	1110	1180	1020	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	61	41.8	58.2	13.3	49.5	
	Copper metal	---	1	2	4	4	
	Aluminum	---	1	1	1	1	
	60/40 Solder	---	1	1	1	1	
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 5

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Nitrogen

Temperature : 105 °C

**Description :**

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	1,890	2,640	2,610	3,110	1,947	
	Ult. elongation, %	510%	644%	668%	651%	625%	
	Modulus, psi	890	855	849	916	1,150	
	Swell ratio, %	32.2	27.5	28.6	17.9	18.2	
	Gel content, %	74%	66.9%	53.0%	65.3%	68.6%	
	Appearance	Colorless Clear	1	1	1	2	
Optical	Total optical, %T						
	UV cutoff, nm	355	356	356	355	341	
	Color *	76.0	75.9	66.0	68.6	70.5	
Elect.	Dielect. Stgth., V/mil	900	1110	1140	1010	1000	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	61	23.5	31.9	29.3	6	
	Copper metal	—	1	1	3	4	
	Aluminum	—	1	1		1	
	60/40 Solder	—	1	1		1	
	Nickel	—					
	Titanium	—					
	Silver	—					

**Notes :**

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 6

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Air

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1000	2.000
	Date :						
	Unit No. :						
	No. of Specimens	10	3	5	5	5	3
Physical	Tensile strength, psi	1,890	1,440	1,290	1,700	1,464	
	Ult. elongation, %	510%	703%	674%	624%	570%	
	Modulus, psi	890	910	905	873	1,030	
	Swell ratio, %	32.2	29.4	19.3	25.4	23.5	
	Gel content, %	74%	51.2%	72.8%	48.8%	54.5%	
	Appearance	Colorless Clear	1	2 <sup>a</sup>	3 <sup>a</sup>	3 <sup>a</sup>	
Optical	Total optical, %T						
	UV cutoff, nm	355	357	357	358	343	369
	Color *	76.0	74.4	53.0	28.5	37.5 <sup>a</sup>	22
Elect.	Dielect. Stgth., V/mil	900	1190	1210	1310	1212	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %	61	46.4		35.6	6	
	Copper metal	—	3.7	3	4.6.7	4.6.7	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Silver	—					

Notes : a. small spots of dark color appear on the surface of the copper and also a few on the solder.

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 7

**Exposure Condition : Thermal Aging**

**Material : EVA**

**Notebook No: A9018**

**Atmosphere : Nitrogen**

**Temperature : 130 °C**

**Description :**

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No. :					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	1,890	1,500	1,320	2,070	1,295
	Ult. elongation, %	510%	656%	723%	558%	643%
	Modulus, psi	890	752	836	915	904
	Swell ratio, %	32.2	11.1	22.4	9.2	16.6
	Gel content, %	74%	35.0%	50.8%	77.7%	61.5%
	Appearance	Clear colorless	1	2 <sup>a.</sup>	3 <sup>a.</sup>	3 - 4 <sup>a.</sup>
Optical	Total optical, %T					
	UV cutoff, nm	355	352	356	361	348
	Color *	76.0	67.8	65.1	26.5	22.8 <sup>a.</sup>
Elect.	Dielect. Stgth., V/mil	900	680	745	1100	950
	Leak current, uA	0	0	0	0	0
Corrosion *	Copper dust, %T					6
	Copper metal	---	1	3.	4	4.5.7
	Aluminum	---	1	1	1	1
	60/40 Solder	---	1	1	1	1
	Nickel	---				
	Titanium	---				
	Silver	---				

**Notes :** a. Small yellow spots are visible on the EVA surface, but are sparse in number. Occasional dark spots on the copper surface and solder also.

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

**ORIGINAL PAGE 19  
OF POGR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 6

Exposure Condition : Thermal Aging

Material : EMA

Notebook No: 13439

Atmosphere : Air

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	4	5	5		
Physical	Tensile strength, psi	2,000	2,260	2,940	2,500	1,999	
	Ult. elongation, %	570%	628%	654%	645%	590%	
	Modulus, psi	3,240	3,580	3,000	3,250	3,580	
	Swell ratio, %	11.2	17.3	14.6	20.3	11.1	
	Gel content, %	62%	51.8%	52.8%	48.8%	69.8%	
	Appearance	Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	354	358	358	356	356	
	Color *	73.0	70.5	67.3	65.6	68.3	
Elect.	Dielect. Stgth., V/mil	900	1030	1070	1120	1110	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	69	61.9	41.5	23.3	18.3	
	Copper metal	—	1	1	2	2	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

**ORIGINAL PAGE 13  
OF POOR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 9

Exposure Condition : Thermal Aging

Material : EMA

Notebook No: 13439

Atmosphere : Nitrogen

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No.:						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	2,000	2,390	2,670	2,530	2,510	
	Ult. elongation, %	570%	652%	640%	650%	630%	
	Modulus, psi	3,240	3,600	3,250	3,280	3,333	
	Swell ratio, %	11.2	13.9	21.5	23.9	9.7	
	Gel content, %	62%	59.1%	41.1%	29.4%	68.5%	
	Appearance	Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	354	356	357	359	358	
	Color *	73.0	64.3	55.7	48.7	43.2	
Elect.	Dielect. Stgth., V/mil	900	1070	1030	1200	1100	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	69	55.5	46.9	37.2	33.4	
	Copper metal	—	1	1	1	1	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 10

Exposure Condition : Thermal Aging

Material : EMA

Notebook No: 13439

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	2,000	2,340	2,220	2,300	2,750	
	Ult. elongation, %	570%	650%	655%	575%	640%	
	Modulus, psi	3,240	4,160	3,950	3,370	3,650	
	Swell ratio, %	11.2	23.4	20.0	22.2	21.4	
	Gel content, %	62%	38.0%	44.1%	44.4%	43.2	
	Appearance	Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	354	361	358	361	360	
	Color *	73.0	51.5	57.7	56.4	53.2	
Elect.	Dielect. Stgth., V/mil	900	1340	1210	1080	1110	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	69	26.5	18.7	12.6	10.2	
	Copper metal	—	2	3	4.5	4.5	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 11

Exposure Condition : Thermal Aging

Material : EMA

Notebook No: 13439

Atmosphere : Nitrogen

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	2,000	2,550	2,640	2,390	2,408	
	Ult. elongation, %	570%	594%	603%	591%	617%	
	Modulus, psi	3,240	3,340	3,250	3,660	3,210	
	Swell ratio, %	11.2	22.6	21.8	20.9	21.6	
	Gel content, %	62%	41%	32.5%	42.0%	44.0	
	Appearance	Clear	1	1	hazy	hazy	
Optical	Total optical, %T						
	UV cutoff, nm	354	359	359	359	358	
	Color *	73.0	49.4	54.1	44.8	43.1	
Elect.	Dielect. Stgth., V/mil	900	1280	1070	890	920	
	Leak current, uA	0	0	0	0	0	
Corrosion *	Copper dust, %T	69	38.6	36.1	21.8	17.3	
	Copper metal	—	1	2	2	3	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE NO  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Exposure Condition : Thermal Aging

Table 11

Material : EMA

Notebook No: 13439

Atmosphere : Air

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No. :					
	No. of Specimens	10	3	5	5	5
Physical	Tensile strength, psi	2,000	1,870	1,430	1,750	1,784
	Ult. elongation, %	570%	657	457%	533%	520%
	Modulus, psi	3,240	3,470	4,050	3,500	4,690
	Swell ratio, %	11.2	23.4	18.4	17.3	11.5
	Gel content, %	62%	36.4%	45.4%	48.6%	65.1%
	Appearance	Clear	hazy	2	3, hazy	3, hazy
Optical	Total optical, %T					
	UV cutoff, nm	354	367	361	358	362
	Color *	73.0	33.8	42.2	40.1	31.3
Elect.	Dielect. Stgth., V/mil	900	1070	1120	1140	1150
	Leak current, uA	0	0	0	0	0
Corrosion *	Copper dust, %T	69	53.4		4.6.7	4.6.7
	Copper metal	—	1		4.7	4.7
	Aluminum	—	1		1	1
	60/40 Solder	—	1		1	1
	Nickel	—				
	Titanium	—				
	Silver	—				

Notes :

1 = no change  
2 = faint color  
3 = moderate color

4 = strong color  
5 = degraded  
extreme degradation

7 = melted  
8 = broken  
9 = surface cracks

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No. 6072.1

POLYMER AGING STUDIES

Table 13

Exposure Condition : Thermal Aging

Material : EMA

Notebook No: 13439

Atmosphere : Nitrogen

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No. :					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	2,000	2,160	1,080	1,330	1,755
	Ult. elongation, %	570%	578%	430%	378%	587%
	Modulus, psi	3,240	3,080	3,290	3,200	3,600
	Swell ratio, %	11.2	13.4	15.7	12.0	8.9
	Gel content, %	62%	62.4%	52.9%	77.2%	69.8%
	Appearance	Clear	1	2	3-4	3-4
Optical	Total optical, %T					
	UV cutoff, nm	354	359	363	368	370
	Color *	73.0	60.5	20.4	10.4	10.2
Elect.	Dielect. Stgth., V/mil	900	940	1100	870	920
	Leak current, uA	0	0	0	0	0
Corrosion *	Copper dust, %T	69	25.8	5.8	0	4.7
	Copper metal	—	1	5	4.5	4.7
	Aluminum	—	1	1	1	1
	60/40 Solder	—	1	1	2	2
	Nickel	—				
	Titanium	—				
	Silver	—				

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 14

Exposure Condition : Thermal Aging

Material : PU Z-2591

Notebook No: 2591

Atmosphere : Air

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	160	183	273	201	199	
	Ult. elongation, %	115%	114%	192%	138%	142%	
	Modulus, psi	254	180	225	248	234	
	Swell ratio, %	2.7	3.4	2.6	2.9	3.5	
	Gel content, %	93.2%	96.6%	96.6%	96.7%	95.7%	
	Appearance	Clear	1	1	2	2	
Optical	Total optical, %T						
	UV cutoff, nm	366	363	369	366	349	
	Color *	63.6	66.9	59.7	54.0	59.1	
Elect.	Dielect. Stgth., V/mil	215	261	238	228	320	
	Leak current, uA	0.2	0.3	0.5	0.1	0.1	
Corrosion *	Copper dust, %T	57	52.2	42.5	30.9	42.3	
	Copper metal	—	1	1	2	2	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change      4 = strong color      7 = melted  
2 = faint color    5 = degraded        8 = broken  
3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE 18  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 15

Exposure Condition : Thermal Aging

Material : PC Z-2591

Notebook No:

Atmosphere : Nitrogen

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	160	210	210	157	201	
	Ult. elongation, %	115%	123%	149%	185%	198%	
	Modulus, psi	254	230	237	167	239	
	Swell ratio, %	2.7	3.1	3.4	4.5	3.5	
	Gel content, %	93.2%	96.5%	96.0%	89.2%	95.7%	
	Appearance	Clear	1	1	2	2	
Optical	Total optical, %T						
	UV cutoff, nm	366	367	364	365	354	
	Color *	63.6	71.0	65.5	49.6	40.1	
Elect.	Dielect. Stgth., V/mil	215	199	208	189	300	
	Leak current, uA	0.2	0.3	0.4	1.5	1.5	
Corrosion *	Copper dust, %T	57	56.6	54.2	37.4	25.4	
	Copper metal	—	1	1	2	2	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change      4 = strong color      7 = melted  
2 = faint color    5 = degraded        8 = broken  
3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 16

Exposure Condition : Thermal Aging

Material : PU Z-2591

Notebook No:

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No.:						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	160	180	166	204	170	
	Ult. elongation, %	115%	115%	127%	208%	152%	
	Modulus, psi	254	140	170	172	187	
	Swell ratio, %	2.7	3.3	3.6	3.6	4.6	
	Gel content, %	93.2%	95.7%	95.3%	94.6%	95.8%	
	Appearance	Clear	2	3	sticky. 4	4	
Optical	Total optical, %T						
	UV cutoff, nm	366	361	365	377	368	
	Color *	63.6	66.4	46.3	5.7	2.4	
Elect.	Dielect. Stgth., V/mil	215	268	306	284	368	
	Leak current, uA	0.2	0	0	NT	0	
Corrosion *	Copper dust, %T	57	49.6	20.8	4.6.7	4.5.7	
	Copper metal	—	1	3	4.7	4.7	
	Aluminum	—	1	1	1	1	
	60/40 Solder	—	1	1	1	1	
	Nickel	—			1		
	Titanium	—					
	Silver	—					

Notes :

1 = no change      4 = strong color      7 = melted  
 2 = faint color    5 = degraded        8 = broken  
 3 = moderate color 6 = extreme degradation 9 = surface cracks

ORIGINAL PAGE 13  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 17

Exposure Condition : Thermal Aging

Material : PU Z-2591

Notebook No:

Atmosphere : Nitrogen

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No.:						
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	160	209	215	69	175	
	Ult. elongation, %	115%	158%	190%	199%	215%	
	Modulus, psi	254	221	197	61	166	
	Swell ratio, %	2.7	3.2	3.5	4.0	4.6	
	Gel content, %	93.2%	96.3%	95.7%	91.0%	96%	
	Appearance	Clear	1	2	3-4	4	
Optical	Total optical, %T						
	UV cutoff, nm	366	363	362	374	361	
	Color *	63.6	65.6	61.5	8.5	7.2	
Elect.	Dielect. Stgth., V/mil	215	222	220	263	379	
	Leak current, uA	0.2	0	0.3	0.5	0.1	
Corrosion *	Copper dust, %T	57	45.0	17.6	4.6, 7	4.6, 7	
	Copper metal	---	1	2	4.6, 7	4.6, 7	
	Aluminum	---	1	1	1	1	
	60/40 Solder	---	1	1	1	1	
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change      4 = strong color      7 = melted  
 2 = faint color    5 = degraded        8 = broken  
 3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 18

Exposure Condition : Thermal Aging

Material : PU Z-2591

Notebook No:

Atmosphere : Air

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No.:						
	No. of Specimens	10	5	5	5	END	
Physical	Tensile strength, psi	160	182	142	-0-		
	Ult. elongation, %	115%	191%	370%	-0-		
	Modulus, psi	254	130	50	-0-		
	Swell ratio, %	2.7	3.8	5.1	n/a		
	Gel content, %	93.2%	95%	86.7%	n/a		
	Appearance	Clear	3	sticky 3-4	destroyed 4.7	END	
Optical	Total optical, %T						
	UV cutoff, nm	366	369	414	4.6.7		
	Color *	63.6	24.2	0.5	brown		
Elect.	Dielect. Stgth., V/mil	2:5	308	317	(6)NT		
	Leak current, uA	0.2	0	0	NT		
Corrosion *	Copper dust, %T	57	4.6.7	4.6.7	4.6.7		
	Copper metal	---	3	4.6.7	4.6.7		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---			1		
	Titanium	---					
	Silver	---					

Notes :

- |                    |                         |                    |
|--------------------|-------------------------|--------------------|
| 1 = no change      | 4 = strong color        | 7 = melted         |
| 2 = faint color    | 5 = degraded            | 8 = broken         |
| 3 = moderate color | 6 = extreme degradation | 9 = surface cracks |

ORIGINAL PAGE 18  
OF POOP QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 19

Exposure Condition : Thermal aging

Material : PU Z-2591

Notebook No:

Atmosphere : Nitrogen

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No.:						
	No. of Specimens	10	5	5	8	END	
Physical	Tensile strength, psi	160	172	149	(5)		
	Ult. elongation, %	115%	195%	387%	(5)		
	Modulus, psi	254	152	60	(5)		
	Swell ratio, %	2.7	3.9	5.1	NT		
	Gel content, %	93.2%	95.5%	86.6%	NT		
	Appearance	Clear	3	4, sticky	4, 6, 7	END	
Optical	Total optical, %T				NT		
	UV cutoff, nm	366	368	403	NT		
	Color *	63.6	25.2	0.1	NT		
Elect.	Dielect. Stgth., V/mil	215	250	233	NT		
	Leak current, uA	0.2	0	0	NT		
Corrosion *	Copper dust, %T	57	0.3	NT	NT		
	Copper metal	—	4	6.7	6.7		
	Aluminum	—	1	1	NT		
	60/40 Solder	—	1	1	NT		
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change      4 = strong color      7 = melted  
 2 = faint color    5 = degraded        8 = broken  
 3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 20

Exposure Condition : Thermal Aging

Material : BA 13870

Notebook No:

Atmosphere : Air

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No.:					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	293	70	80	90	82
	El. elongation, %	110	40	40	50	53
	Modulus, psi	90	147	160	136	164
	Swell index, %	2.8	2.95	2.68	2.82	2.74
	Gel content, %	95.2	96.9	93.1	96.7	95.3
	Appearance	Clear	1	1	1	1
Optical	Total optical, %T					
	UV cutoff, nm	380	380	381	380	384
	Color %T-400 nm	56%	59.0	48.1	51.2	46.5
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	0
Corrosion	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Out of range

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE 18  
OF POOR QUALITY

Project No. 6070.1

POLYMER AGING STUDIES

Table 21

Exposure Condition : Thermal Aging

Material : BA 13870

Notebook No:

Atmosphere : Nitrogen

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No.:					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	290	100	80	90	91
	Ult. elongation, %	110	60	40	50	62
	Modulus, psi	90	134	158	137	137
	Swell index, %	2.8	2.94	2.84	2.92	2.91
	Gel content, %	95.2	93.8	94.6	95.6	95.1
	Appearance	Clear	1	1	1	1
Optical	Total optical, %T					
	UV cutoff, nm	380	378	380	380	384
	Color %T-400 nm	56 %	59.9	49.9	53.5	53.0
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	0
Corrosion	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Out of range

1 = no change      4 = strong color      7 = melted  
2 = faint color    5 = degraded        8 = broken  
3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 22

Exposure Condition : Thermal Aging

Material : BA 13870

Notebook No:

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No. :					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	293	80	80	70	81
	Ult. elongation, %	110	40	50	50	54
	Modulus, psi	90	112	147	151	157
	Swell index, %	2.8	2.79	2.93	2.95	2.85
	Gel content, %	95.2	95.0	94.9	94.7	93.1
	Appearance	Clear	1	1	1	1
Optical	Total optical, %T					
	UV cutoff, nm	380	380	380	374	383
	Color %T-400 nm	56 %	56.7	46.5	55.5	50.0
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	a.
Corrosion	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Out of range

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 60-2.1

POLYMER AGING STUDIES

Table 23

Exposure Condition : Thermal Aging

Material : BA 13870

Notebook No:

Atmosphere : Nitrogen

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No. :					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	293	80	70	70	76
	Ult. elongation, %	110	50	50	40	51
	Modulus, psi	90	151	99	110	152
	Swell index, %	2.8	2.93	3.0	2.90	2.93
	Gel content, %	95.2	94.4	94.2	95.0	94.7
	Appearance	Clear	1	1	1	1
Optical	Total optical, %T					
	UV cutoff, nm	380	380	380	380	384
	Color %T-400 nm	56 %	48.8	60.8	46.3	41.0
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	a.
Corrosion *	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Out of range

1 = no change      4 = strong color      7 = melted  
 2 = faint color    5 = degraded        8 = broken  
 3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 0072.1

POLYMER AGING STUDIES

Table 24

Exposure Condition : Thermal Aging

Material : BA 13870

Notebook No:

Atmosphere : Air

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No.:					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	293	80	80	100	79
	Ult. elongation, %	110	50	50	60	50
	Modulus, psi	90	157	154	149	157
	Swell index, %	2.8	3.26	2.82	2.75	2.76
	Gel content, %	95.2	90.6	95.1	93.4	91.9
	Appearance					
Optical	Total optical, %T					
	UV cutoff, nm	380	379	381	378	377
	Color %T-400nm	56 %	51.0	41.7	24.2	38.0
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	a.
Corrosion *	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Out of range

- |                    |                         |                    |
|--------------------|-------------------------|--------------------|
| 1 = no change      | 4 = strong color        | 7 = melted         |
| 2 = faint color    | 5 = degraded            | 8 = broken         |
| 3 = moderate color | 6 = extreme degradation | 9 = surface cracks |

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 25

Exposure Condition : Thermal Aging

Material : BA 13870

Notebook No:

Atmosphere : Nitrogen

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date :					
	Unit No. :					
	No. of Specimens	10	5	5	5	5
Physical	Tensile strength, psi	293	90	80	80	82
	Ult. elongation, %	110	60	50	60	53
	Modulus, psi	90	149	127	157	157
	Swell index, %	2.8	2.94	2.93	2.93	3.76
	Gel content, %	95.5	94.7	94.0	95.0	92.0
	Appearance	Clear	1	1	1	1
Optical	Total optical, %T					
	UV cutoff, nm	380	380	381	377	384
	Color %T-400 nm	56 %	50.5	36.3	34.4	31.0
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	a.
Corrosion	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Out of range

1 = no change      4 = strong color      7 = melted  
2 = faint color    5 = degraded        8 = broken  
3 = moderate color   6 = extreme degradation   9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 26

Exposure Condition : RS/4 DRY

Material : EVA

Notebook No: 48901C

Atmosphere : Air

Temperature : 50 °C

Description : Prototype forulation of A9918

Candidate pottant

Specimen	Exposure, Hrs.	0 (control)	15,520	22,720	30,000	35,000	40,000
	Date : (add 4Khrs)						
	Unit No. :	4	4	4	1	5	5
	No. of Specimens	1	1	1	1	1	1 End
Physical	Tensile strength, psi	1,890	1,590	1,580	1,450	1,480	1,479
	Ult. elongation, %	677 %	600%	605 %	480%	864%	718
	Modulus, psi	at 100% strain 360	450	833	a.	a.	a.
	Swell Ratio		b.	b.	12.9	12.0	11.5
	Gel content, %	72%	b.	b.	45 %	83.9%	63.2
	Appearance	Clear	ok	ol	ok	(c)	(c)
Optical	Total optical, %T						
	UV cut off, nm	362	b.	365	367	365	372
	Color %T-400 nm	76.0	b.	b.	b.	23.4%	4%
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.	a.
	Leak current, ma		a.	a.	a.	a.	a.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :  
a. insufficient specimen available  
b. not measured  
c. specimen clear w/ faint yellow color, flexible,  
but small surface cracks forming.

1 = no change      4 = strong color      7 = melted  
2 = fair color      5 = degraded      8 = broken  
3 = moderate color      6 = extreme degradation      9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 27

Exposure Condition : RS/4 - DRY

Material : EVA

Notebook No: 14747

Atmosphere : Air

Temperature : 50 °C

Description : EVA formula 9918 replacing UV531 with UV-2098 : candidate pottant

Specimen	Exposure, Hrs.	0 (control)	2,000	4,000	6,000	8,000	12,000
	Date :						
	Lot No.:	43	3	3	3	3	3
	(Starting No.) No. of Specimens	20	15	10	7	3	3
Physical	Tensile strength, psi	2,490	2,640	3,300	3,250	3,200	2,933
	Ult. elongation, %	585%	634	635	652	670	700
	Modulus, psi	875	629	666	490	665	952
	Swell Ratio	7.1	15.6	17.5	17.7	18.6	23.5
	Gel content, %	80.5%	71%	86.4%	69.0%	72.4	77.2
	Appearance	Clear sheet	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	358	358	357	357	356	357
	Color, %T 400 nm	72%	39.7%	44.8%	52.5%	59.8	68%
Elect.	Dielect. Stgth., V/mil		a.				
	Leak current, ma		a.				
Corrosion *	Copper dust, %T	na	na	na			
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. insufficient sample

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 28

Exposure Condition: RS/4 DRY

Material: PU Z-2591

Notebook No: 14600

Atmosphere: Air

Temperature: 50 °C

Description:

Specimen	Exposure, Hrs.	0 (control)	12,000	14,000			
	Date:				END		
	Unit No.:	2	2	2			
	No. of Specimens	10	1	1			
Physical	Tensile strength, psi	160	290	153			
	Ult. elongation, %	115	230	170			
	Modulus, psi	254	229	200			
	Swell index, %	2.7	3.2	3.8			
	Gel content, %	93.2%	95.3	97.8			
	Appearance	Yellow	3	3			
Optical	Total optical, %T						
	UV cutoff, nm	366	365	365			
	Color = %T-400 nm	63.6	24.9%	21.4			
Elect.	Dielect. Stgth., V/mil		a.	a.			
	Leak current, m*		a.	a.			
Corrosion +	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes: a. insufficient specimen

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

**ORIGINAL PAGE 18  
OF POOR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 29

Exposure Condition : RS/4 DRY

Material : Tedlar 200BS30WH Notebook No: 14321-3

Atmosphere : Air Temperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	4,320	6,648	8,000	10,000	15,000
	Date :						
	Unit No. :	8	8	5	5	5	5
	Remaining No. of Specimens	10	12	8	6	4	3
Physical	Tensile strength, psi	14,000	14,500	14,600	14,300	6,900	1,630
	Ult. elongation, %	59	68	62	65	73	55
	Modulus, psi	$2.8 \times 10^5$	a.	$2.3 \times 10^5$	$2.7 \times 10^5$	$7 \times 10^4$	8,600
	Swell Ratio	N/A	n/a	n/a	n/a	n/a	n/a
	Gel content, %	N/A	n/a	n/a	n/a	n/a	n/a
	Appearance	White film	1	1	1	1	1
Optical	Total optical, %T	Opaque	n/a	n/a	n/a	n/a	n/a
	UV cutoff, nm	N/A	n/a	n/a	n/a	n/a	m/a
	Color *	White	1	1	1	1	1
Elect.	Dielect. Stgth., V/mil		b.	b.	b.	b.	b.
	Leak current, ma		b.	b.	b.	b.	b.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. not measured  
b. insufficient sample

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 30

Exposure Condition : RS/4 DRY

Material : Scotchpar 20CP

Notebook No: 14321-2

Atmosphere : Air

Temperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	4,320	6,648	8,000	10,000	15,000
	Date :						
	Unit No. :	8	8	5	5	5	5
	Remaining No. of Specimens	10	12	8	6	4	4
Physical	Tensile strength, psi	29,400	28,000	28,000	25,600	12,570	2,020
	Ult. elongation, %	27	15	20	15	1	2
	Modulus, psi	$3.6 \times 10^5$	a.	a.	$5 \times 10^5$	$1 \times 10^5$	$1.8 \times 10^4$
	Swell Ratio	Soluble	n/a	n/a	n/a	n/a	n/a
	Gel content, %	Soluble	n/a	n/a	n/a	n/a	n/a
	Appearance	White film	1	1	1	1	1
Optical	Total optical, %T	Opaque	n/a	n/a	n/a	n/a	n/a
	UV cutoff, nm	n/a	n/a	n/a	n/a	n/a	n/a
	Color *	White	1	1	1	1	1
Elect.	Dielect. Stgth., V/mil		b.	b.	b.	b.	b.
	Leak current, ma		b.	b.	b.	b.	b.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. not measured  
b. insufficient sample

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE 18  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 31

Exposure Condition : RS/4 85°C

Material : EVA-9918

Notebook No: 16168-A

Atmosphere : Air

Temperature : 85 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	500	1,000	2,500	4,000	6,000
	Date :						
	Unit No.:	6	6	6	6	6	
	No. of Specimens	15	5	5	3	3	
Physical	Tensile strength, psi	1,890	2,510	5,090	3,266	3,259	
	Ult. elongation, %	510	600	640	640	650	
	Modulus, psi	890	880	1,240	988	1,090	
	Swell ratio, %	32	19.5	16.7	17.1	14.5	
	Gel content, %	74%	72.3	68.1	80.6	82.8	
	Appearance	clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	355	355	348	358	354	
	Color *, %T-400nm	76%	62.3	67.1	51.5	62	
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T	n/a					
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change

4 = strong color

7 = melted

2 = faint color

5 = degraded

8 = broken

3 = moderate color

6 = extreme degradation

9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6372.1

POLYMER AGING STUDIES

Table 32

Exposure Condition : RS/4-85

Material : EVA/L101/Glass Notebook No: 16724

Atmosphere : Air Temperature : 85 °C

Description : EVA crosslinked with Lupersol-101 behind Sunadex glass

Specimen	Exposure, Hrs.	0 (control)	1,000				
	Date :						
	Unit No. :	6	6	End			
	No. of Specimens	8					
Physical	Tensile strength, psi	3,000		Test terminated at 1,000 hours : Specimens are stuck to glass, have flowed and discolored. Pale yellow color .			
	Ult. elongation, %	650					
	Modulus, psi	850					
	Swell index, %	15					
	Gel content, %	78%					
	Appearance	Clear					
Optical	Total optical, %T						
	UV cutoff, nm	n/a					
	Color *	80%					
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminium	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

- |                    |                         |                    |
|--------------------|-------------------------|--------------------|
| 1 = no change      | 4 = strong color        | 7 = melted         |
| 2 = faint color    | 5 = degraded            | 8 = broken         |
| 3 = moderate color | 6 = extreme degradation | 9 = surface cracks |

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No.                     

**POLYMER AGING STUDIES**

Table 33

**Exposure Condition : RS/4 - 85**

**Material : EVA 16718B**

**Notebook No: 16724**

**Atmosphere : Air**

**Temperature : 85 °C**

**Description : EVA with TBEC and UV-2098, no Tinuvin-770**

Specimen	Exposure, Hrs.	0 (control)	1.000				
	Date :						
	Unit No. :	4	1				
	No. of Specimens	11	11	END			
Physical	Tensile strength, psi	3.400	Test terminated at 1.000 hours ; specimens have little tensile strength. high surface tack, cannot be tested. No color formation				
	Ult. elongation, %	600					
	Modulus , psi	850					
	Swell index , %	7.5	5.78				
	Gel content , %	82%	47.8				
	Appearance	Cl-ar					
Optical	Total optical , %T						
	UV cutoff , nm	356					
	Color, %T-400 nm	76 %					
Elect.	Dielect. Stgth., V/mil						
	Leak current , ma						
Corrosion +	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 34

Exposure Condition : RS/4 85°C

Material : EMA 15257C

Notebook No: 16168-C

Atmosphere : Air

Temperature : 85 °C

Description : EMA cured w/ TBEC. fully compounded

Specimen	Exposure, Hrs.	0 (control)	500	1,000	2,500	4,000	6,000
	Date :						
	Unit No.:	6	6	6	6	6	
	No. of Specimens	10	5	5	3	3	
Physical	Tensile strength, psi	2,850	2,980	4,840	2,555	2,720	
	Ult. elongation, %	640	590	630	580	630	
	Modulus, psi	3,480	827	402	3,400	4,160	
	Swell index, %	11.4	6.2	6.5	9.6	8.2	
	Gel content, %	81%	73.2	71.4 %	60.9	69.1	
	Appearance	Clear	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	351	358	350	361	357	366
	Color %T 400 nm	65%	75.8	71.8	54.5	63	16
Elect.	Dielect. Stgth., V/mil		n/a	n/a	n/a	n/a	n/a
	Leak current, ma						
Corrosion	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE #  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 35

Exposure Condition : RS/4 85°C

Material : PU Z-2591

Notebook No: 16168-B

Atmosphere : Air

Temperature : 85 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	500	1,000	2,000	3,000	5,000
	Date :						
	Unit No. :	6	6	6	6	6	6
	No. of Specimens	15	4	3	3	3	3
Physical	Tensile strength, psi	160	200	170	290	187	283
	Ult. elongation, %	115	150	130	150	180	440
	Modulus, psi	254	228	239	219	216	93.8
	Swell index, %	2.7	3.1	4.2	5.2	3.8	4.4
	Gel content, %	93.2%	93.1	92.4	96.6 %	95.6	95.2
	Appearance	Faint yellow.	1	1	2	2	3
Optical	Total optical, %T						
	UV cutoff, nm	366	367	371	372	373	372
	Color, %T-400nm	63.6	48.9	48.8	24	28.5	15
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 36

Exposure Condition : RS/4 85°C

Material : BA 13870

Notebook No: 16168-D

Atmosphere : Air

Temperature : 85 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	500	1,000	2,000	3,000	5,000
	Date :						
	Unit No. :	5	6	6	6	6	6
	No. of Specimens	15	4	3	3	3	3
Physical	Tensile strength, psi	293	80	100	100	87	55
	Ult. elongation, %	110	60	60	45	55	30
	Modulus, psi	90	118	138	115	166	130
	Swell index, %	2.4	2.6	2.8	2.8	2.9	2.8
	Gel content, %	86%	89.2	90.1	91.5 %	92.8	95.1
	Appearance	Clear	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	385	371	363	349	343	339 <sup>a</sup>
	Color *, %T-400nm	31.4	52.0	65.6	44.8	42.5	55
Elect.	Dielect. Stgth., V/mil		n/a	n/a	n/a	n/a	n/a
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. low point, %T = 5%

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

**ORIGINAL PAGE IS  
OF POOR QUALITY**

Project No. 6072.1

**POLYMER AGING STUDIES**

Table 37

**Exposure Condition : CER**

**Material : EVA 9918**

**Notebook No:**

**Atmosphere : Air**

**Temperature : 55 °C**

**Description :**

Specimen	Exposure, Hrs.	0 (control)	500	1,000	2,000	3,000	4,000
	Date :						
	Unit No.:	B	B	B	B	B	B
	No. of Specimens	15	5	5	5	2	2
Physical	Tensile strength, psi	1,890	3,410	3,390	5,320	2,887	2,677
	Ult. elongation, %	510	620	660	640	650	630
	Modulus, psi	890	667	665	783	860	823
	Swell index, %	32.2	18.7	22.3	17.5	20.0	4.75 d.
	Gel content, %	74 %	73.6	71.4	77.5%	63.6	4.4 d.
	Appearance	1	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	355	356	353	348	312	298
	Color %T 400 nm	76.0	50.4%	44.3%	34.2	9%	25
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

b. 500 hours added due to lamp maintenance.

d. Very low gel and swell values, may be inaccurate due to losses

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 38

Exposure Condition : CER

Material : EMA 15257

Notebook No:

Atmosphere : Air

Temperature : 50 °C

Description : EMA 15295 is identical to No. 13439 except the Lucersol 101 replaced w/TBEC

Specimen	Exposure, Hrs.	0 (control)	500	1,000	2,000	3,000	4,000 <sup>b</sup>
	Date :						
	Unit No. :	A	A	A	A	A	A
	No. of Specimens	15	5	5	5	2	3
Physical	Tensile strength, psi	2,850	3,000	3,380	5,050	2,727	2,901
	Ult. elongation, %	640	590	600	610	620	650
	Modulus, psi	3,480	4,820	2,840	4,930	860	5,260
	Swell index, %	11.4	7.8	6.9	5.36	6.3	9.2
	Gel content, %	81%	83%	80.1%	79.4%	80.4	81.7
	Appearance	Clear	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	351	363	368	367	371	365
	Color %T-400 nm	65%	15%	5.1% <sup>a</sup>	12.2	10	15
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion +	Copper dust, %T						
	Copper metal	---					
	Aluminium	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. specimen does not appear yellow. The loss of transmission comes from the development of haze. Specimens quite white in appearance.  
b. 500 Hours added due to lamp maintenance

1 = no change      4 = strong color      7 = melted  
2 = faint color      5 = degraded      8 = broken  
3 = moderate color      6 = extreme degradation      9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 39

Exposure Condition: OPT

Material: EVA 9918

Notebook No:

Atmosphere: Air

Temperature: 90 °C

Description:

Specimen	Exposure, hrs.	0 (control)	1,000	2,000	2,500		
	Date:						
	Unit No.:	B	B	B	B	END	
	No. of Specimens	10	25	5	5		
Physical	Tensile strength, psi	1,890	2,527	a.	a.		
	Ult. elongation, %	510	590	a.	a.		
	Modulus, psi	890	1,190	a.	a.		
	Swell index, %	32.2	12.0	14.8	9.0		
	Gel content, %	74	60.3	85.7	42.4		
	Appearance	Clear	1	1	Hazy		
Optical	Total optical, %T						
	UV cutoff, nm	355	354	358	358		
	Color *	76.0	45	28	14		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes: a. Specimen too degraded to be tested. No color.

1 = no change      4 = strong color      7 = melted  
2 = faint color      5 = degraded      8 = broken  
3 = moderate color      6 = extreme degradation      9 = surface cracks

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 40

Exposure Condition : OPT

Material : EVA 16718-B

Notebook No: 16729

Atmosphere : Air

Temperature : 90 °C

Description : EVA/TBEC/UV2098 no Tinuvia 770

Specimen	Exposure, Hrs.	0 (control)	1,000				
	Date :						
	Cont No. :	B	B				
	No. of Specimens		12	END			
Physical	Tensile strength, psi	3,658	a.				
	Ult. elongation, %	600	a.				
	Modulus, psi	810	a.				
	Swell index, %	8.1	797				
	Gel content, %	83.4	95.5				
	Appearance	Clear	6.7				
Optical	Total optical, %T						
	UV cutoff, nm	358	a.				
	Color, %T-400 nm	72%	a.				
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. Materials too degraded to perform tests. Polymer has "cheesy" consistency, removed by scraping off the OPT surface.

1 = no change      4 = strong color      7 = melted  
2 = faint color    5 = degraded        8 = broken  
3 = moderate color   6 = extreme degradation   9 = surface cracks

C-2

ORIGINAL PAGE 19  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 41

Exposure Condition : OPT

Material : EMA 15257

Notebook No:

Atmosphere : Air

Temperature : 90 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000		
	Date :					
	Unit No. :	B	B	B		
	No. of Specimens	10	25	10	END	
Physical	Tensile strength, psi	2,850	1,752	a.		
	Ult. elongation, %	640	490	a.		
	Modulus, psi	3,480	3,970	a.		
	Swell index, %	11.4	9.9	6.4		
	Gel content, %	81%	61.1	72%		
	Appearance	Clear	1	9		
Optical	Total optical, %T					
	UV cutoff, nm	351	368	366		
	Color *	65%	12	12%		
Elect.	Dielect. Stgth., V/mil					
	Leak current, ma					
Corrosion *	Copper dust, %T					
	Copper metal	---				
	Aluminum	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
	Silver	---				

Notes : a. Polymer has yellow color and "cheesy" consistency. Removed from further testing.

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE 13  
OF POOR QUALITY

Project No. 6-77-1

POLYMER AGING STUDIES

Table 42

Exposure Condition : OPT

Material : PU Z-2591

Notebook No:

Atmosphere : Air

Temperature : 90 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No. :	B	B	B			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	160	162	a.			
	Ult. elongation, %	115	233	a.			
	Modulus, psi	254	139	a.			
	Swell index, %	2.7	4.2	3.5			
	Gel content, %	93.2	95.0	93.7			
	Appearance	Faint yellow	Yellow	V. Tacky!			
Optical	Total optical, %T						
	UV cutoff, nm	366	372	380			
	Color *	63.3	15	11%			
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper Just, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. Mechanical properties appear to be OK. but the specimens have aggressive surface tack and cannot be handled for testing.

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 43

Exposure Condition : OPT

Material : EVA 9918

Notebook No:

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No. :	C	C	C			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	1,890	1,885				
	Ult. elongation, %	510	550				
	Modulus, psi	890	1,200				
	Swell index, %	32.2	16.1	16.2			
	Gel content, %	74.0	80.7	69%			
	Appearance	Clear	2	6.7. tacky			
Optical	Total optical, %T						
	UV cutoff, nm	355	353	358			
	Color %T 400	76.0	38	15%			
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

- |                    |                         |                    |
|--------------------|-------------------------|--------------------|
| 1 = no change      | 4 = strong color        | 7 = melted         |
| 2 = faint color    | 5 = degraded            | 8 = broken         |
| 3 = moderate color | 6 = extreme degradation | 9 = surface cracks |

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 44

Exposure Condition : OPT

Material : PU Z-2591

Notesbook No:

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No. :	C	C	C			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	160	220	a.			
	Ult. elongation, %	115	255	a.			
	Modulus, psi	254	195	a.			
	Swell index, %	2.7	3.8	5.1			
	Gel content, %	93.2	98.5	86.3			
	Appearance	Faint yellow	2	6. tacky			
Optical	Total optical, %T						
	UV cutoff, nm	366	373	370			
	Color *	63.3	27	19%			
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

ORIGINAL PAGE 18  
OF POOR QUALITY

Project No. 4072

POLYMER AGING STUDIES

Table 45

Exposure Condition: OPT

Material: EMA 15257

Notebook No:

Atmosphere: Air

Temperature: 105°C

Description:

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date:						
	Unit No.:	C	C	C			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	2,850	1,420	a.			
	Ult. elongation, %	640	455	a.			
	Modulus, psi	3,480	3,110	a.			
	Swell index, %	11.4	15.9	7.1			
	Gel content, %	81%	65.9	79.0			
	Appearance	Clear	1	9			
Optical	Total optical, %T						
	UV cutoff, nm	351	367	385			
	Color %T-400 nm	65%	15	6%			
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion*	Copper dust, %T		n/a	n/a			
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes: a. Degraded, "ch--sy" consistency

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

ORIGINAL PAGE IS  
OF POOR QUALITY

Project No. 6072.1

POLYMER AGING STUDIES

Table 46

Exposure Condition: OPT

Material: EVA 16718-B

Notebook No: 16729

Atmosphere: Air

Temperature: 105 °C

Description: EVA/TBEC/UV2098

No Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000				
	Date :			This material removed from further testing due to severe degradation occurring within 200 hours of exposure .			
	Unit No. :	C	C				
	No. of Specimens		12				
Physical	Tensile strength, psi	3,658	a.				
	Ult. elongation, %	600	a.				
	Modulus, psi	810	a.				
	Swell index, %	8.1	887				
	Gel content, %	83.4%	67.1				
	Appearance	Clear	"melted"				
Optical	Total optical, %T						
	UV cutoff, nm	358					
	Color, %T-400 nm	72%					
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. Cannot be tested due to flow of specimens. No yellow color . surface tack noticable . "cheesy" consistency .

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

Table 47  
ADHESIVE BOND STRENGTH  
Measured by ASTM D-903 or ASTM D-1876

Resin : EVA 9918		Cure Conditions Time / Temp. (min.) (°C)	Bond Strength Pounds per inch of Width		
Notebook Number:	Bonded to:		Control Value	Water Immersion (350 hrs)	Boiling Water (2 hrs)
A11861-2A	Glass/EVA 9918	20 150°	39.6 c	37.9 c	27.1 c
A11866-A	Glass/EVA 9918 w/blend		35.4 c	41.9 c	-
A11894-3	Galvanized/EVA 9918		2.5 a	NT	NT
A11894-4	Mild Steel/EVA 9918		56.0 c	42.6 c	50.7 c
A11895-1	Aluminum/EVA 9918		41.9 c	2.3 c	2.6 c
A11894-1	EVA 9918/Tedlar 100RG30UT		4.5 a	NT	NT
A11894-2	EVA 9918/Korad 212		1.1 a	NT	NT
A11894-1	EVA 9918/Sunadex		34.8 c	broke	32.3 c
A13881-1	EVA 9918/Tedlar 200RS30M		-	-	-
A13881-2	EVA 9918/Tedlar 200PT		8.25 a	11.1 a	10.8 a
A13881-3	EVA 9918/Tedlar 100RG30UT		6.14 a	tore	7.8 a
14316-1	EVA 9918/Scotchpar 20CP		11.5 a	26.8	1.09 a
14316-3	EVA 9918/Korad 63000		1.65 a	NT	NT
14316-4	EVA 9918/Tedlar 100RG30UT		v. high	12.6 a	high
14316-6	EVA 918/mild steel		2.26 c	2.28	3.07 a
14719-a, b, c	EVA/Scotchpar 20CP		35.7 c	31.3 c	21.3 c
16170-5	Plexiglas V811 acrylic		5.61 a	7.8 a	5.49 a
16160-3	Copper		5.11 a	40.7 c	3.90 a
16153-1	Tedlar 100RG30UT		13.0 c	6.28 a	6.5 c
16160-1	Solder		0	NT	NT
16180-6	Copper		32.5 c	43.4 c	37.6 c
16180-7	Solder		46.8 c	4.35 a	5.4 a
16174-1	Korad 63000		film broke	film broke	v. low
16174-4	Korad 63000		x.f.	5.4 a	film broke
16174-5	Acrylar 22417		x.	film broke	x.f.
16174-6	Plexiglas V811		40.2 a	42.4 a	44.1 a
16185-7	Nickel		-	4.2 a	-
16187ARS	Sunadex glass		8.3 a	9.3 a	14 a
16722-1	Acrylar 22417		5.6 c	x.	3.1 a
16721-1	Aluminum		6.5 a	3.7 a	3.2 a

( Cont. Ined )

a. Adhesive failure at interface c. Cohesive failure NT. Not tested

x. Too little to be tested f. No delamination upon bending

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 4B  
ADHESIVE BOND STRENGTH III  
Measured by ASTM D-903 or ASTM D-1876

Resin :	EVA A9918 - Continued		Cure Conditions Time / Temp. (min.) (°C)	Bond Strength Pounds per inch of Width		
	Notebook Number :	Bonded to :	Primer / Adhesive	Control Value	Water Immersion (350 ltrs)	Boiling Water (2 ltrs)
16722-7	16722-7	Tedlar 100RG30UT	107D	x	x	9.0
16723-1	16723-1	Kynar 460	68040	5.7	6.1	4.1
16723-2	16723-2	Wicket	11861	1.5	1.4	1.6
16735-1A	16735-1A	Sunadex	Cavco-F	0	NT	NT
16735-1B	16735-1B	Sunadex	Cavco-M	0	NT	NT
16735-1C	16735-1C	Sunadex	Cavco-M1	0	NT	NT
16723-6	16723-6	Conner	16160	7.2	4.7	2.6
16723-5	16723-5	Solder	16160	9.8	9.0	7.7
16723-4	16723-4	Solder	16180	5.4	3.8	3.4
16733-A1	16733-A1	Aluminum-sanded	5% Z-6020/H <sub>2</sub> O pH 7.0	12.2	a	
16733-A3	16733-A3	as in 16733-A1 but prime, heat at 100°C/ 20 min; reprime, dry, bond		9.9	a	
16733-B1	16733-B1	Aluminum-sanded	5% Z6030/H <sub>2</sub> O pH 7.0	11.4	a	
16733-B2	16733-B2	16733-B1, but prime, heat at 100°C/20min, reprime, dry and bond		12.1	a	

a. Adhesive failure at interface      c. Cohesive failure      NT. Not tested  
x. Too brittle to be tested      f. No delamination upon bending

ORIGINAL PAGE 19  
OF POOR QUALITY

Table 4)  
ADHESIVE BOND STRENGTH  
Measured by ASTM D-903 or ASTM D-1876

Resin: EVA/TBAC (15295)		Cure Conditions Time / Temp. (min.) / (°C)	Bond Strength Pounds per inch of Width		
Notch Number:	Bonded to:		Control Value	Water Immersion (350 Hrs)	Boiling Water (2 Hrs)
15295 A,B,C	Sunplex glass Mild steel Acrylar 22417 Aluminum Mild steel	20 150"	51.3	32.9	31.3
16186 A,B			15.6		4.6
16222-2			6.8	5.4	3.4
16721-2			5.6	3.0	3.0
16723-3			8.0	5.2	2.3

a. Adhesive failure at interface c. Cohesive failure NT. Not tested  
x. Too brittle to be tested f. No delamination upon bending

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 50  
ADHESIVE BOND STRENGTH  
Measured by ASTM D-903 or ASTM D-1876

Resin : EWA 13439	Notebook Number:	Bonded to :	Primer / Adhesive	Cure Conditions Time / Temp. (min.) (°C)	Bond Strength Pounds per Inch of Width			
					Control Value	Water Immersion (350 hrs)	Boiling Water (2 hrs)	
A1381-4		Tedlar 1000G300T	68040	20 150°	0.47	NT	NT	
A1381-5		Tedlar 2008S300H	68040		1.88	NT	NT	
14316-2		Scotchpar 10CP	107D		0.8	0.4	1.2	
14316-5		Tedlar 1000G300T	107D		0.77	NT	NT	
14316-7		Mild steel	11861		5.64	14.6	13.9	
14316-8		Senedex glass	11861		60.2	40	27.7	
Resin:		EWA/TBEC (15257)						
15257 A,B,C		Senedex glass	A11861	20 150°				
16182-4		Flexiglas V811	16170			64.2	45.5	
16182-2		Mild steel	11861		3.6	low	6.4	
16182-6		Nickel	11861		35.1	low	2.8	
16182-5		Acrylicar X22417	16170		12.3	4.7	7.1	
16182-3		Tedlar 1000G300T	68040		film broke	x.	film broke	
16722-3		Tedlar 1000G300T	14719		2.7	3.6	3.3	
16722-4		Scotchpar 20CPW	14719		5.0	6.8	1.5	
16722-5		Tedlar 1000G300T	107D		1.5	1.2	1.8	
16722-6		Scotchpar 20CPW	107D		1.5	1.3	1.5	

a. Adhesive failure at interface c. Cohesive failure NT. Not tested  
x. Too brittle to be tested f. No delamination upon bending

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 51  
ADHESIVE BOND STRENGTH<sup>II</sup>  
Measured by ASTM D-903 or ASTM D-1876

Resin : BRETHANE PU-Z-2591		Cure Conditions Time / Temp. (min.) / (°C)	Bond Strength Pounds per Inch of Width			
Notebook Number:	Bonded to:		Control Value	Water Immersion (350 Hrs)	Boiling Water (2 Hrs)	
14559-0a	Tedlar 100MG30UT	12 Hr 23°	0	NT	NT	
14559-0b	Scotchpar 20MP		0	NT	NT	
14559-0c	Korad 630000		0	NT	NT	
14559-0d	Sunadex glass		0	NT	NT	
14559-1a	Tedlar 100MG		4.8	2.5	0	a
14559-1b	Scotchpar 20CP		0.2	NT	NT	
14559-1c	Korad 63000		3.1			
14316-9	Sunadex glass		31.4	37.2	45.2	c
14566-3	Tedlar 100MG30		4.8	0.6	2.5	a
14566-2	Korad 63000		4.14	2.55	2.7	a
16185-8	Scotchpar 20 CPW		low	low	low	

a. Adhesive failure at interface      c. Cohesive failure      NT. Not tested  
x. Too brittle to be tested      f. No delamination upon bending

ORIGINAL PAGE 19  
OF POOR QUALITY

Table 52  
ADHESIVE BOND STRENGTH  
Measured by ASTM D-903 or ASTM D-1876

Resin : Notebook Number :	RUTYL ACRYLATE (13870) Bonded to :	Primer / Adhesive	Cure Conditions Time / Temp (min.) (°C)	Bond Strength Pounds per inch of Width		
				Control Value	Water Immersion (350 Hrs)	Boiling Water (2 Hrs)
14559-2A	Tedlar 1008G30UT Korad 63000	none	12 Hrs 23°	0	NT	NT
	Scotchpar 20CP	none		0	NT	NT
	Sunadex glass	none		0	NT	NT
14559-2C	Tedlar 1008G30UY	26032W		2.35	2.35	2.27
14559-2E	Scotchpar 20CP	26032W		1.53	NT	a
14559-2B	Korad 63000	26032W		0.71	NT	NT
14559-2D	Sunadex glass	26032W		0.90	0.36	0.59
14588-3A	Sunadex glass	14588		3.0	1.2	1.4
16174-2	Acrylar 2241	none		0	NT	NT
16174-3	Acrylar 22417	16170		low	NT	NT
16185-71	Korad 63000	16170		8.3	x.	3.4
16174-8a	Aluminum	14588		0	NT	NT
16174-8b	Copper	14588		0	NT	NT
16174-8c	Solder	14588		0	NT	NT
16174-8d	Mild steel	14588		0	NT	NT
16185-8	Tedlar 1008G30UT	14588		1.3	x.	0.8
16185-9	Acrylar 22417	68040		v. low	v. low	NT
16186-11	Tedlar 1008G30UT	68040		x.	x.	x.
16186-10	Tedlar 1008G30UT treated w/68040	14588		x.	x.	x.
16186-12	Korad 63000	68040		x.	x.	x.

a. Adhesive failure at interface c. Cohesive failure NT. Not tested  
x. Too brittle to be tested f. No delamination upon bending  
1. The Korad 63000 swells and softens.

ORIGINAL PAGE 10  
OF POOR QUALITY

Table 51  
ADHESIVE BOND STRENGTH II  
Measured by ASTM D-903 or ASTM D-1876  
SELF PRIMING POTANTS (Bonded to Sunadex at 150°C/ 20 min.)

Notchmark number	EVA	Primer/ adhesive 7-6030	Control value		Pounds per inch of width at break (psi)	
			350 hrs water Immersion		2 hrs Boiling water	
16177-A	9918	0.25 hr two months storage	42	44	39	37
16177-B	9918	0.1 hr two months storage	33	26.8	34	31.7
16177-C	9918	0.05 hr two months storage	29	24	16	28.4
					27.9	23.6
					30.4	26
						34.3
16171-A	15295	0.25 hr two months storage	31	31.8	33.7	44
16171-B	15295	0.1 hr two months storage	24.9		17.9	24.3
16171-C	15295	0.05 hr two months storage	10.9	9.5	6.1	6.1
					8.4	8.6
16171-D	EVA	0.25 hr two months storage	57.4	58	16.8	56.9
16171-E	15257	0.1 hr two months storage	60.9	43.5	57.2	43.3
16171-F	15257	0.05 hr two months storage	49.0	39.3	39.2	58
					30.7	46.4
						45.5
						34.5

a. adhesive failure      c. cohesive failure

Table 54

**ADHESIVE AND PRIMER FORMULATIONS**  
(Evaluated at Springborn Labs)

<u>Number</u>	<u>Formulation</u>	<u>Intended For</u>
1. A11861	Z-6030            90 parts BDMA              10 parts Lupersol 101      1 part	EVA, EMA-glass
Dilute to 10% in methanol, anhydrous *		
2. 68040	Proprietary, DuPont	EVA/Tedlar
3. 107D	Cymel 303        90 parts Z-6040            10 parts Methanol          300 parts	EVA-polyester
4. Z-6020	Z-6020            10 parts Methanol          90 parts	PU-glass, Tedlar
5. Z-6020W	Z-6020            9.5 parts Water              0.5 parts Methanol          90 parts	PU-glass, Tedlar
6. Z-6032W	Z-6032            25 parts Water              5 parts Acetic Acid        0.2 parts Methanol          20 parts	BA-glass, Tedlar
7. 14588	Z-6020            10 parts Si(OEt) <sub>4</sub> 10 parts IPA                180 parts	BA-glass
8. 14719	Resimene 740                23.75 parts Z-6040            1.25 parts IPA                75.00 parts	EVA-polyester
9. 16170	AT-51             100 parts Z-6020            5 parts Z-6030            1 part Toluene           174 parts (20% active solution)	EVA, EMA to Acrylic
10. 16153	Resimene 740    10.00 parts Z-6040            0.25 parts Z-6030            0.25 parts Methanol          90.00 parts	EVA 9918 to Melinex and Tedlar

\* We have also used a 5% dilution with good results. It might be a better idea because it helps to avoid "over-priming" that reduces the bond strength.

Table 54. Continued

<u>Number</u>	<u>Formulation</u>	<u>Intended for</u>
11. 16160	Isopropanol 75.00 parts Z-6030 24.75 BDMA 0.25	EVA to metals; solder, copper (clean w/ acetone first)
12. 16180	Z-6030 9.9 BDMA 0.1 Zinc Chromate 10.0 Methanol 30.0	

**TABLE 55**

**QUESTIONS FOR**

**Material: Sinadex Low Iron Glass**

**Measurement:** Percent variation in short circuit current ( $I_{sc}$ ) during 24 month exposure period using standard cell.

Exposure:	Months
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
31	31
32	32
33	33
34	34
35	35
36	36
37	37
38	38
39	39
40	40
41	41
42	42
43	43
44	44
45	45
46	46
47	47
48	48
49	49
50	50
51	51
52	52
53	53
54	54
55	55
56	56
57	57
58	58
59	59
60	60
61	61
62	62
63	63
64	64
65	65
66	66
67	67
68	68
69	69
70	70
71	71
72	72
73	73
74	74
75	75
76	76
77	77
78	78
79	79
80	80
81	81
82	82
83	83
84	84
85	85
86	86
87	87
88	88
89	89
90	90
91	91
92	92
93	93
94	94
95	95
96	96
97	97
98	98
99	99
100	100

[illegible]

**Legend:** 0 - control value before exposure; referenced to standard c. 1  
1-24 - number months exposure; % of original short circuit current

ORIGINAL PAGE 18  
OF POOR QUALITY

TABLE 56

Selling Experiments

Material: Tedlar 100SD30VT Film (Supported on glass carrier)

Measurements: Percent variation in short circuit current ( $I_{sc}$ ) during 24 month exposure period using standard cell.

Exposure: Months

Treatment	1981												1982												1983											
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24											
None	0	-2.4	-3.3	-1.0	-3.5	-4.7	-4.7	-5.1	-6.3	-7.7	-8.8	-6.7	-6.5	-5.8	-4.6	-5.0	-4.9	-4.7	-5.8	-4.3	-6.3	-6.3	-4.1	-7.4	-7.4											
L-1668	0	-1.5	-1.5	-2.7	-1.8	-3.8	-2.9	-3.5	-3.7	-6.0	-5.3	-3.9	-4.2	-5.3	-4.6	-5.3	-5.1	-5.0	-5.4	-6.0	-6.0	-4.4	-5.0	-5.4	-6.7											
Osone, then L-1668	0	-0.7	-0.9	-2.1	-2.2	-2.8	-3.1	-3.5	-3.4	-5.9	-5.0	-3.7	-4.8	-5.1	-4.4	-5.0	-5.5	-5.8	-6.2	-5.1	-5.1	-2.3	-4.4	-6.0	-7.1											
E-3820	0	+0.5	0	-3.5	-0.8	-1.5	-1.7	-0.9	-1.3	-2.4	-3.0	-2.1	-2.4	-2.3	-2.3	-1.7	-1.9	-1.6	-1.7	-2.3	-2.8	-0.3	-0.9	-0.5	-3.1											
Osone, then E-3820	0	-3.2	-2.9	+0.3	-2.4	-3.9	-3.7	-4.3	-4.4	-5.8	-6.4	-3.9	-4.1	-4.4	-3.3	-5.6	-5.8	-6.5	-5.8	-5.7	-7.0	-4.3	-4.2	-6.6	-7.1											
OT-650 Glass Resin	0	-2.7	-2.9	-4.1	-3.5	-4.5	-4.6	-7.2	-4.6	-9.1	-6.5	-6.4	-5.6																							
SAC-1080	0	-2.5	-2.4	-3.0	-2.6	-3.7	-3.1	-4.3	-4.5	-7.9	-5.6	-4.5	-4.6																							
ML-81 Resin & Neos	0	-1.2	-3.3	-3.4	-3.0	-4.9	-2.8	-4.3	-3.8	-6.6	-5.2	-4.9	-4.6																							

Legend: 0 - control value before exposure; referenced to standard cell  
1-24 - number months exposure; % of original short circuit current

ORIGINAL PAGE 19  
OF POOR QUALITY

TABLE 57

Soiling Experiments

Material: Acrylar X22417 Film (supported on glass carrier)

Measurement: Percent variation in short circuit current ( $I_{sc}$ ) during 24 month exposure period using standard cell.

Exposure: Months

Treatment	1981												1982												1983											
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24											
None	0	-3.1	-3.9	-4.4	-3.7	-5.1	-5.4	-6.4	-7.5	-10.2	-10.8	-7.9	-7.0	-8.1	-6.4	-7.3	-7.6	-7.3	-7.4	-5.4	-9.8	-6.2	-7.4	-8.2	-9.3											
L-1668	0	-0.8	-0.4	-1.8	-2.1	-3.5	-3.5	-5.0	-3.9	-5.1	-6.6	-5.6	-5.0	-5.0	-3.2	-4.6	-5.0	-4.7	-4.7	-6.4	-6.2	-1.0	-2.6	-5.1	-6.4											
Ozone, then L-1668	0	-2.9	-2.5	-2.8	-2.5	-3.4	-3.2	-4.5	-5.0	-6.3	-6.1	-4.5	-4.6	-6.2	-5.3	-4.8	-5.6	-5.7	-5.3	-7.6	-6.7	-2.8	-6.2	-6.5	-8.0											
E-3820	0	-1.5	-1.6	-2.4	-2.3	-2.8	-2.6	-3.9	-3.9	-6.7	-6.8	-4.4	-5.4	-6.0	-4.3	-4.0	-4.0	-3.6	-5.5	-6.0	-5.7	-1.4	-4.4	-4.6	-7.1											
Ozone, then E-3820	0	-0.8	-2.0	-2.3	-1.8	-2.5	-3.1	-4.0	-3.2	-5.0	-4.9	-3.2	-4.0	-5.0	-3.8	-1.1	-2.1	-1.4	-1.1	-2.6	-3.8	+0.6	-2.0	-1.9	-3.9											
SNC-1000	0	-4.1	-5.2	-6.3	-4.2	-6.5	-6.1	-6.2	-6.6	-8.8	-7.6	-6.1	-7.8																							
WL-81 Robin & Haas	0	-2.6	-3.5	-1.0	-2.6	-3.1	-4.2	-4.7	-4.8	-6.8	-6.3	-4.5	-5.6																							

Legend: 0 - control value before exposure; referenced to standard cell  
1-24 - number months exposure; % of original short circuit current

Table 58

CORROSION MONITORING  
( on Mild Steel plates )

Notebook No.	Test Specimen Materials	Primer system	ASTM B-117 Salt Spray <sup>a</sup>					
			Corrosion Conditions					
			600 Hr	800Hr	1,200Hr	2,000Hr	2,600Hr	3,300Hr
16197-1	None	Alseal 518 fired finish	3, 6, 10	3, 6, 10	3, 6, 10	3, 6, 10	3, 6, 10	3, 6, 10
-2	None	Alseal 518 bead finish	3, 6, 10	3, 6, 10	3, 6, 10	3, 6, 10	3, 6, 10	3, 6, 10
-3	Urethabond-111 ( 2 coats )	Alseal 518	9, 13	10, 13	10, 13	10, 13	10, 13	10, 14
-4	Weacoat 497; Urthabond-111(2)	Alseal 518	9, 11	10, 11	10, 11	10, 12, 14	10, 12, 14	10, 13, 14
-5	Urethabond 104; Ureth. -111 (2)	Alseal 518	10, 13	10, 13	10, 13	10, 13	10, 13	10, 13
-6	Z-2891 ( Dev. Associates)	Alseal 518B Z-6020	10, 13, 14	10, 13, 14	10, 13, 14	10, 13, 14	10, 13, 14	10, 13, 14
-7	Duramar 5MW92377 (PPG)	Alseal 518F 55PLY3305	10, 12	10, 12	10, 13	10, 13, 14	10, 13, 14	10, 13, 14
-8	Dextar 75X102 Silicone	Alseal 518F 9X165 epoxy	10, 12	10, 13	10, 13	10, 13, 14	10, 13, 14	10, 13, 14

a. the recorded observations are for the upper side of the test specimen. The underside of the test specimen is less directly exposed to salt fog and numbers 4, 5, 7 & 8 are all rated (1) out to the 3,300 hour mark.

### Table 5

**CORROSION MONITORING**  
**( on Mild Steel plates )**

Notebook No.	Test Specimen		Primer system
	Materials	Covering material	
16197-1	None	Aalseal 518 flred finish	
-2	None	Aalseal 518 bead finish	
-3	Urethabond-111 ( 2 coats )	Aalseal 518	
-4	Weacoat 497; Urthabond -111(2)	Aalseal 518	
-5	Urëthabond 104; Ureth. -111 (2)	Aalseal 518	
-6	Z-2891 ( Dev.Associates)	Aalseal 518B Z-6020	
-7	Duranar 5MW92377 (PPG)	Aalseal 518F 55PLY3305	
-8	Dextar 75X102 Silicone	Aalseal 518F 9X165 epoxy	

Table 60Corrosion Monitoring Legend

1. No change in appearance
2. Slight dulling of surface
3. Noticeable dulling of surface
4. Light corrosion - some small rust spots showing
5. Medium corrosion - rust spots covering approximately 10% of surface
6. Heavy corrosion - rust covering 1/4 of surface
7. Discoloration of topcoating
8. Light rust along scribe mark
9. Medium rust along scribe mark
10. Heavy rust along scribe mark
11. Slight blistering along scribe mark only, (under 1 mm)
12. Medium blistering along scribe mark only, (1 mm to 5 mm)
13. Heavy blistering along scribe mark only, (over 5 mm)
14. Blistering of coating

Note: \* indicates "white corrosion"

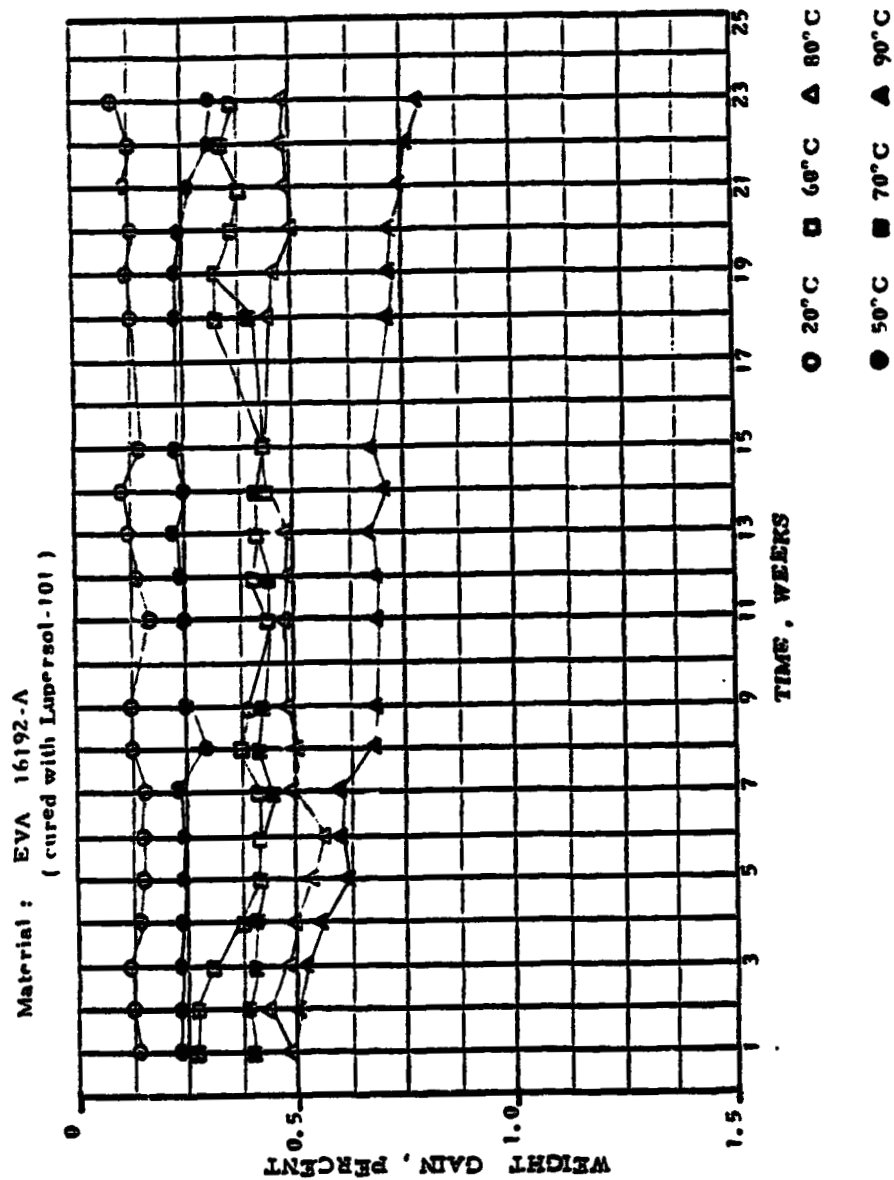
A P P E N D I X B

FIGURES 1 - 8

ORIGINAL PAGE 19  
OF POOR QUALITY

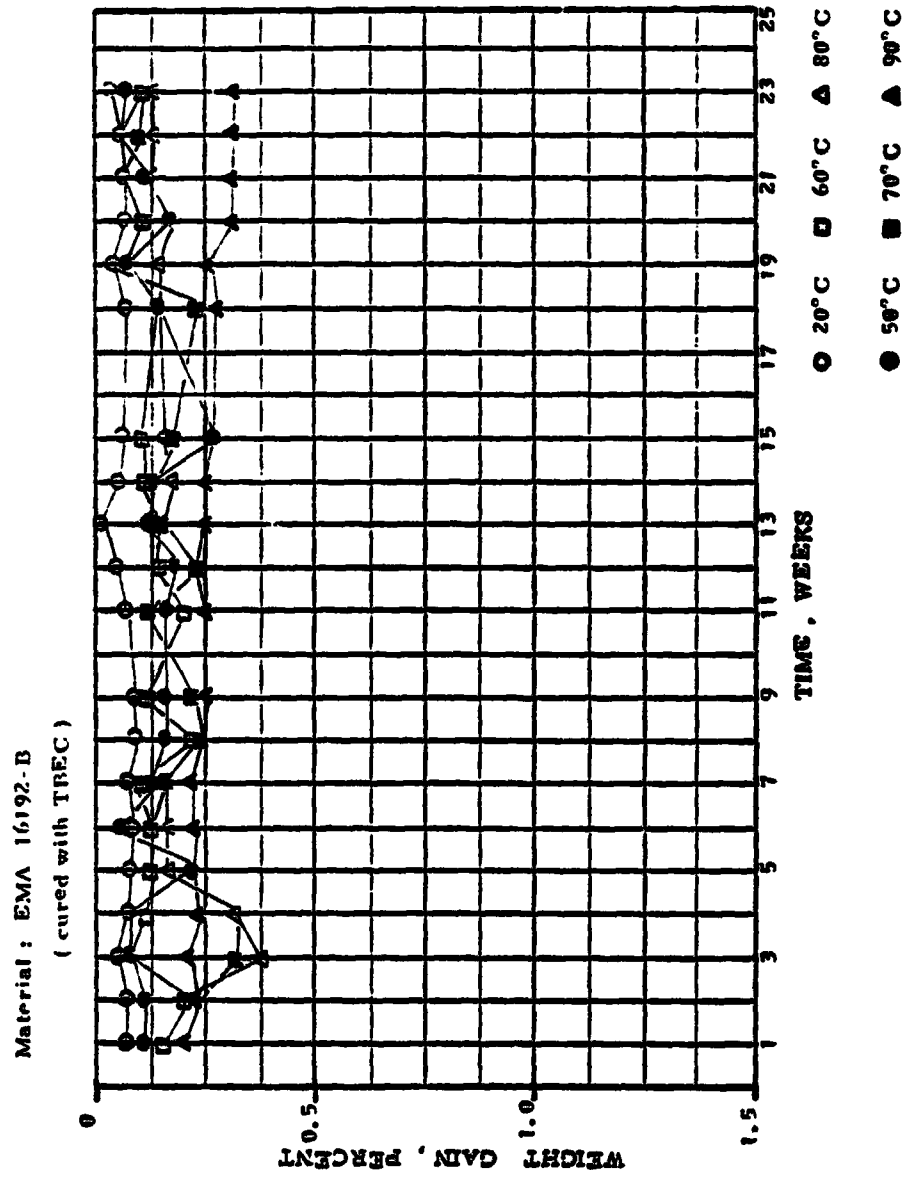
FIGURE 1

WATER ABSORPTION EXPERIMENT



ORIGINAL PAGE IS  
OF POOR QUALITY

FIGURE 2  
WATER ABSORPTION EXPERIMENT



ORIGINAL PAGE 19  
OF POOR QUALITY

FIGURE 3  
WATER ABSORPTION EXPERIMENT

Material : Polyurethane Z-2591

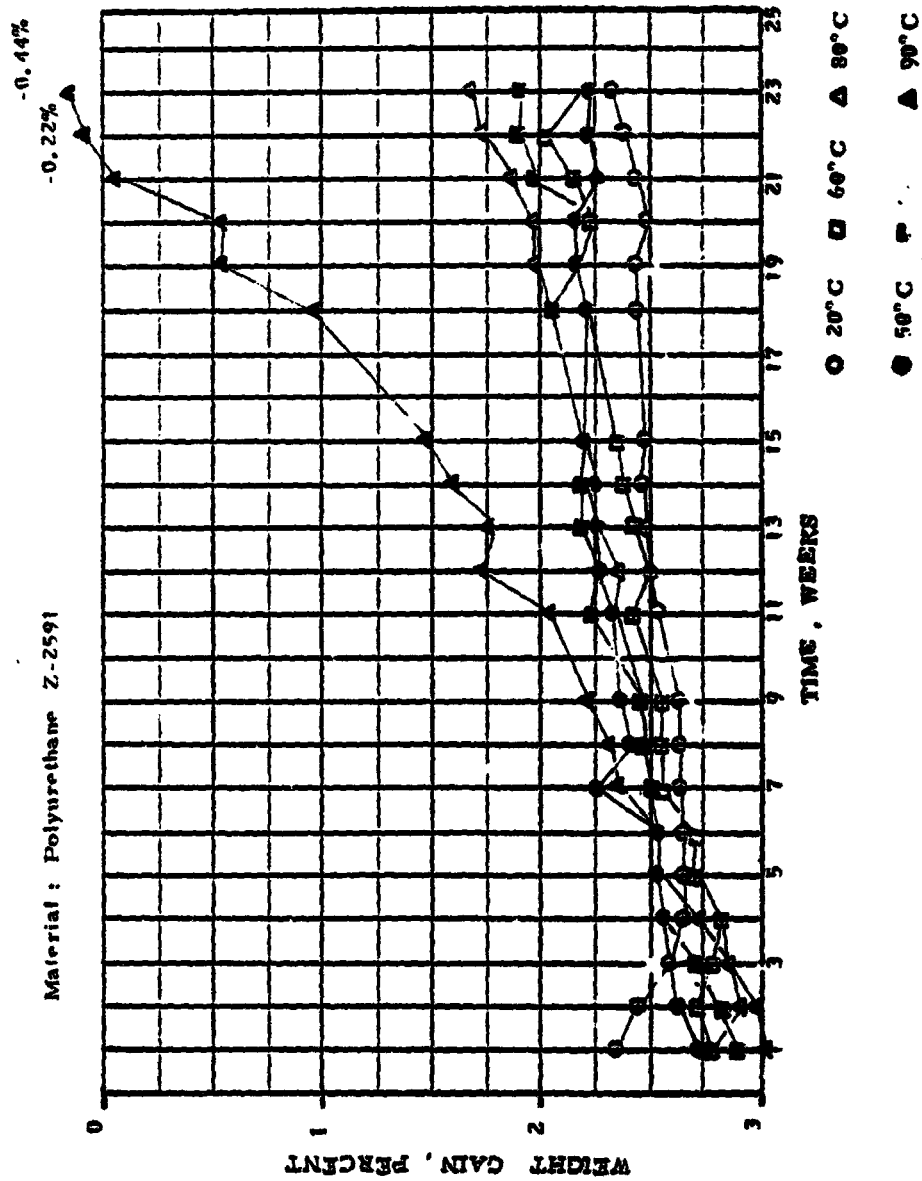
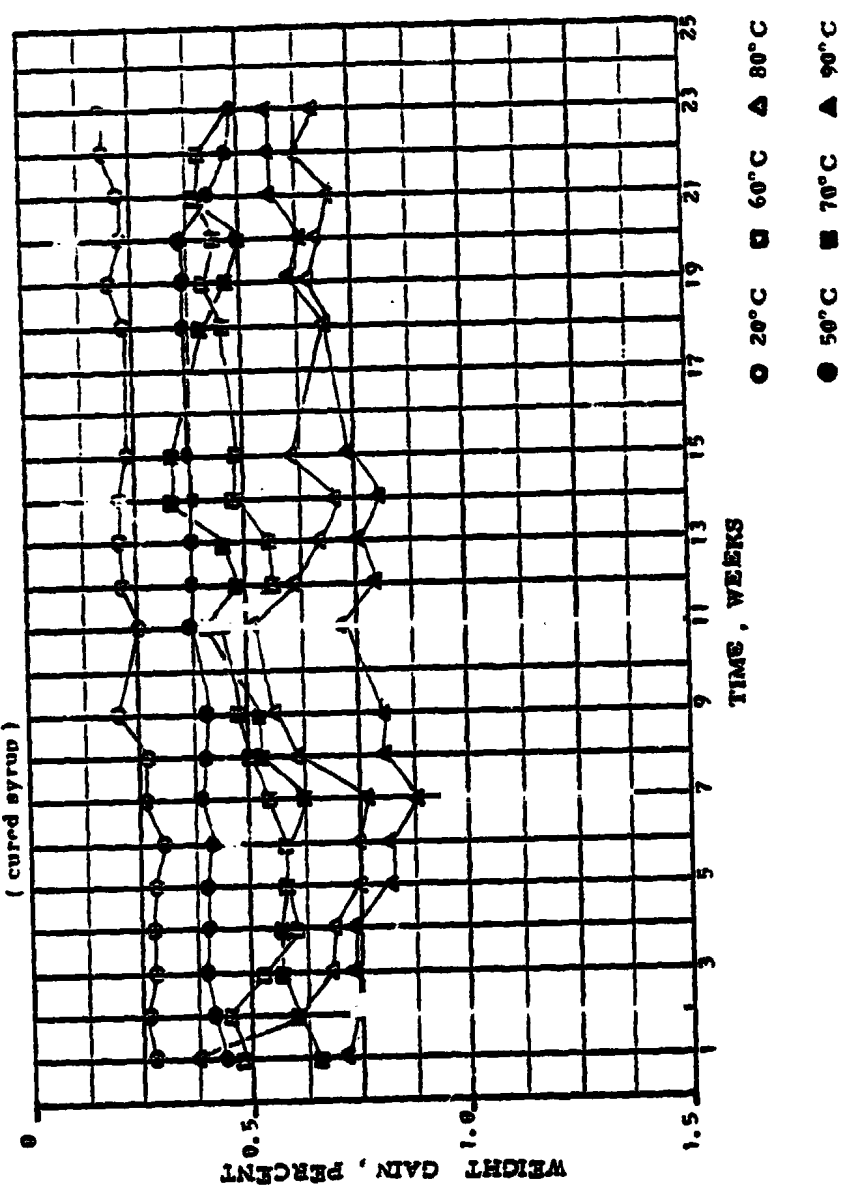


FIGURE 4

WATER ABSORPTION EXPERIMENT

Material: Butyl acrylate 13870  
(cured syrup)



ORIGINAL PAGE IS  
OF POOR QUALITY

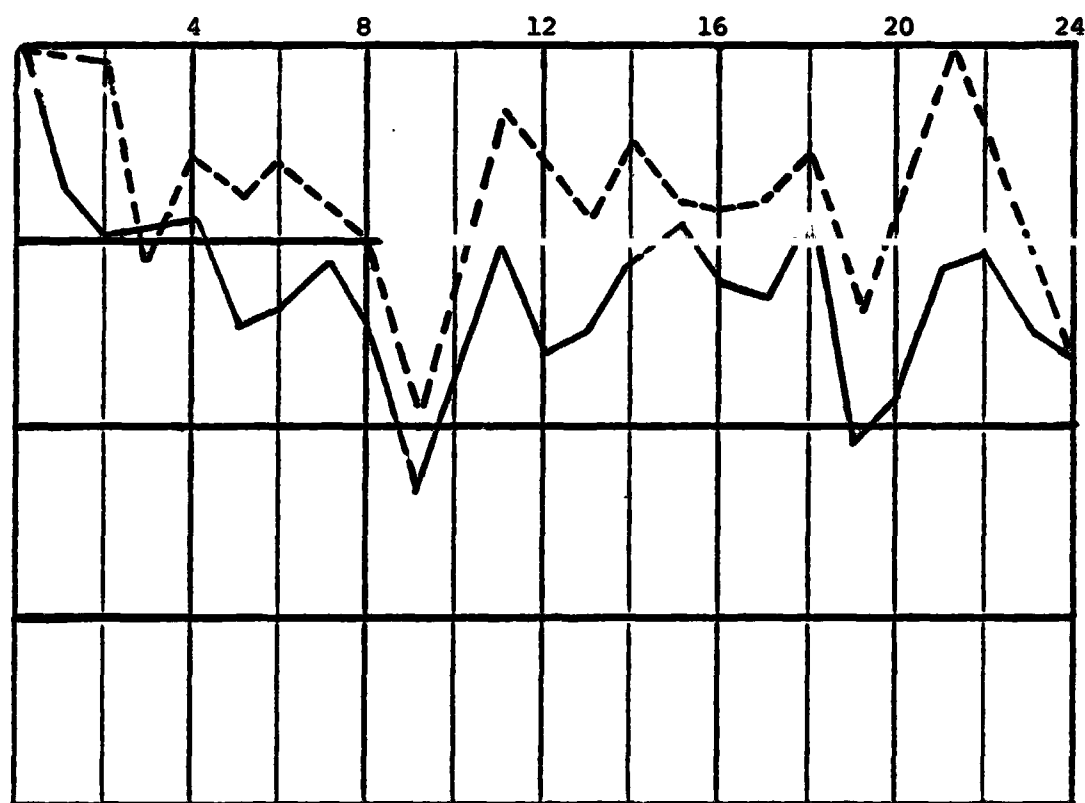
FIGURE 5

Soiling Experiments

Material: Sunadex Low-Iron Glass

Exposure: 24 months, Enfield, Connecticut

Measurement: Percent loss in short circuit current  
( $I_{sc}$ ) with exposure time.



———— Control, untreated  
----- Treated with E-3820

FIGURE 6

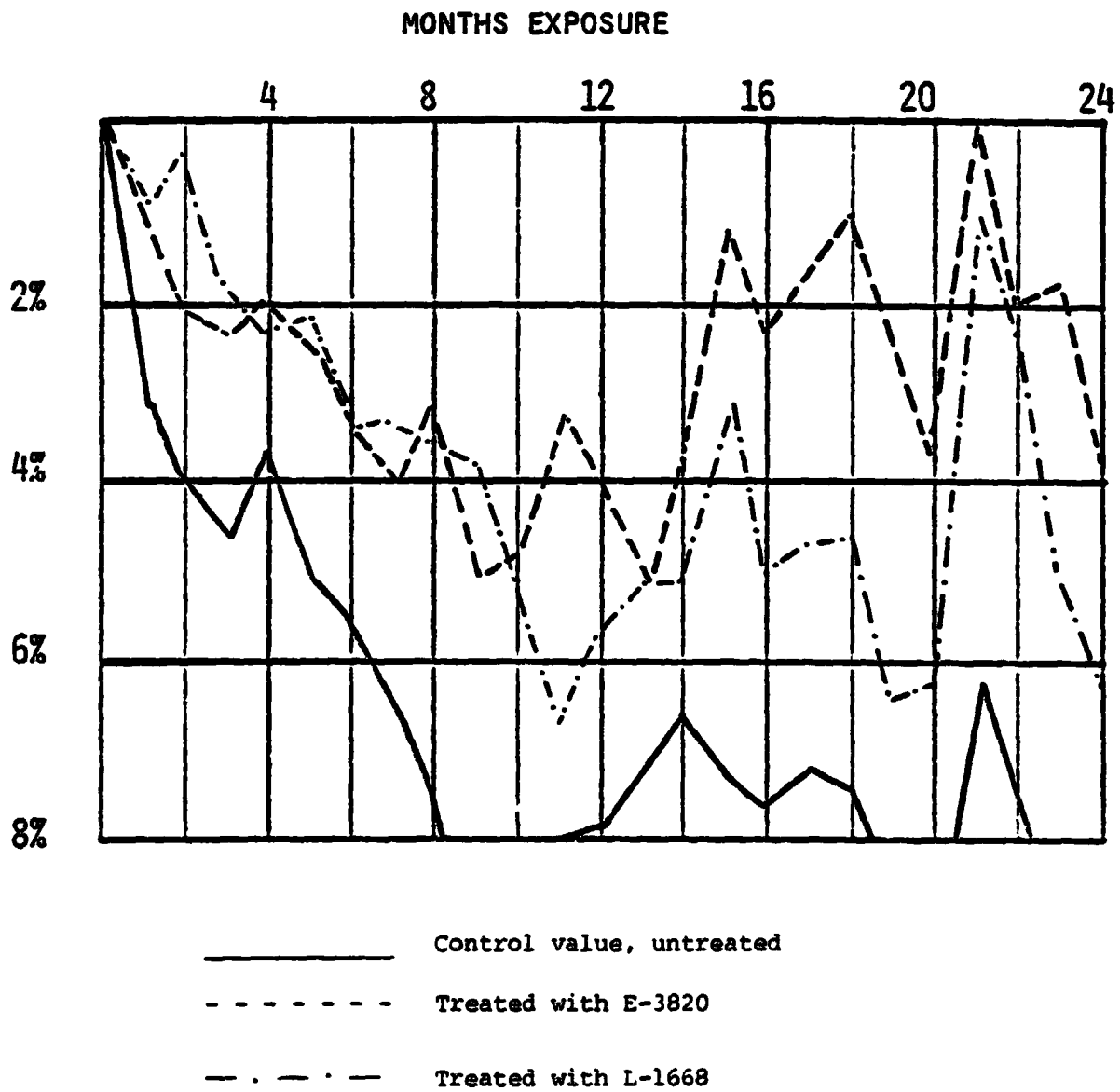
ORIGINAL PAGE 19  
OF POOR QUALITY

Soiling Experiments

Material: Tedlar 100BG30UT  
(supported on glass carrier)

Exposure: 24 months, Enfield, Connecticut

Measurement: Percent loss in short circuit current  
( $I_{sc}$ ) with exposure time.



ORIGINAL PAGE IS  
OF POOR QUALITY

FIGURE 7

Soiling Experiments

Material: Acrylar X-22417 Acrylic Film  
(supported on glass carrier)

Exposure: 24 months, Enfield, Connecticut

Measurement: Percent loss in short circuit current  
( $I_{sc}$ ) with exposure time.

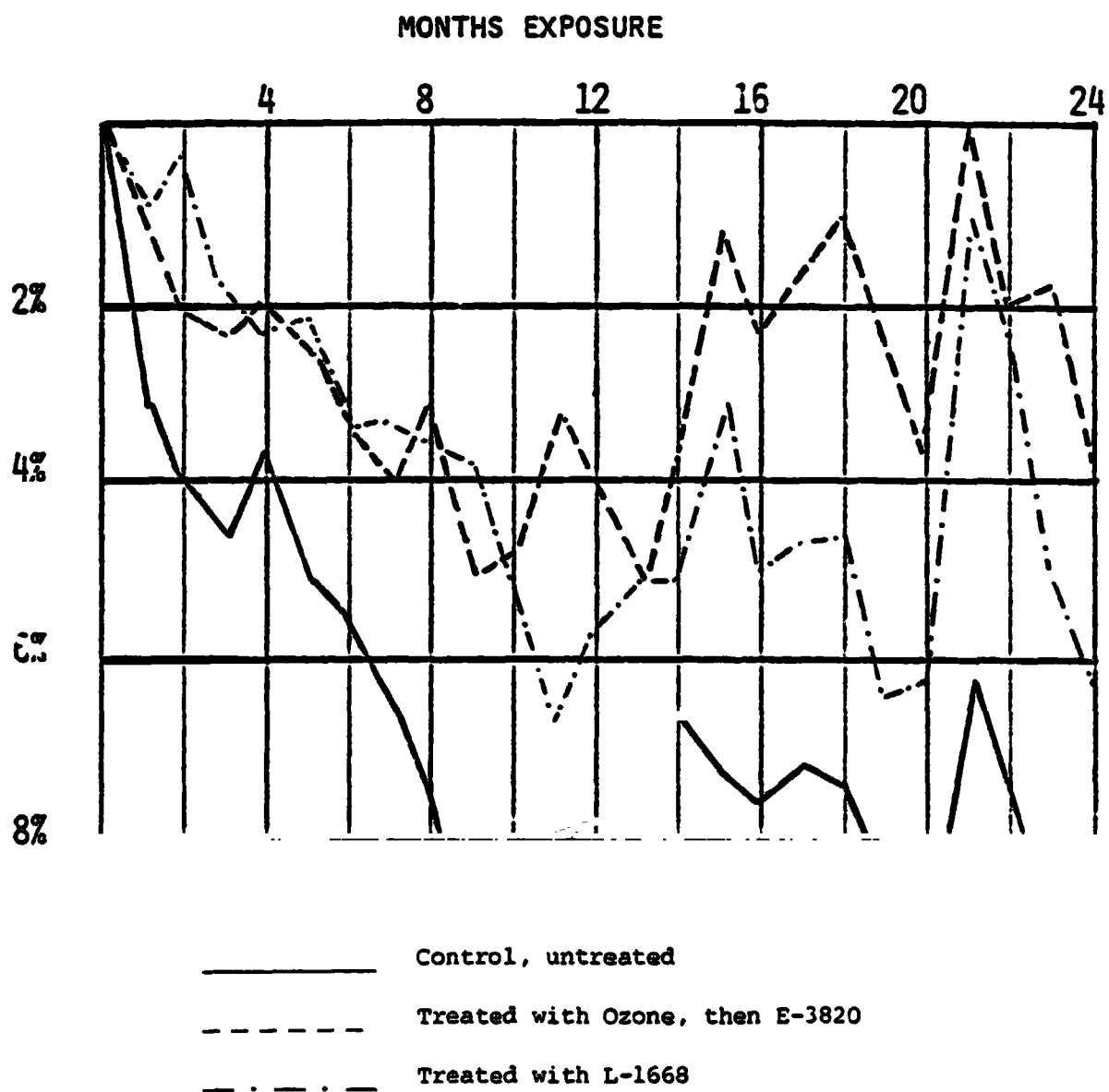


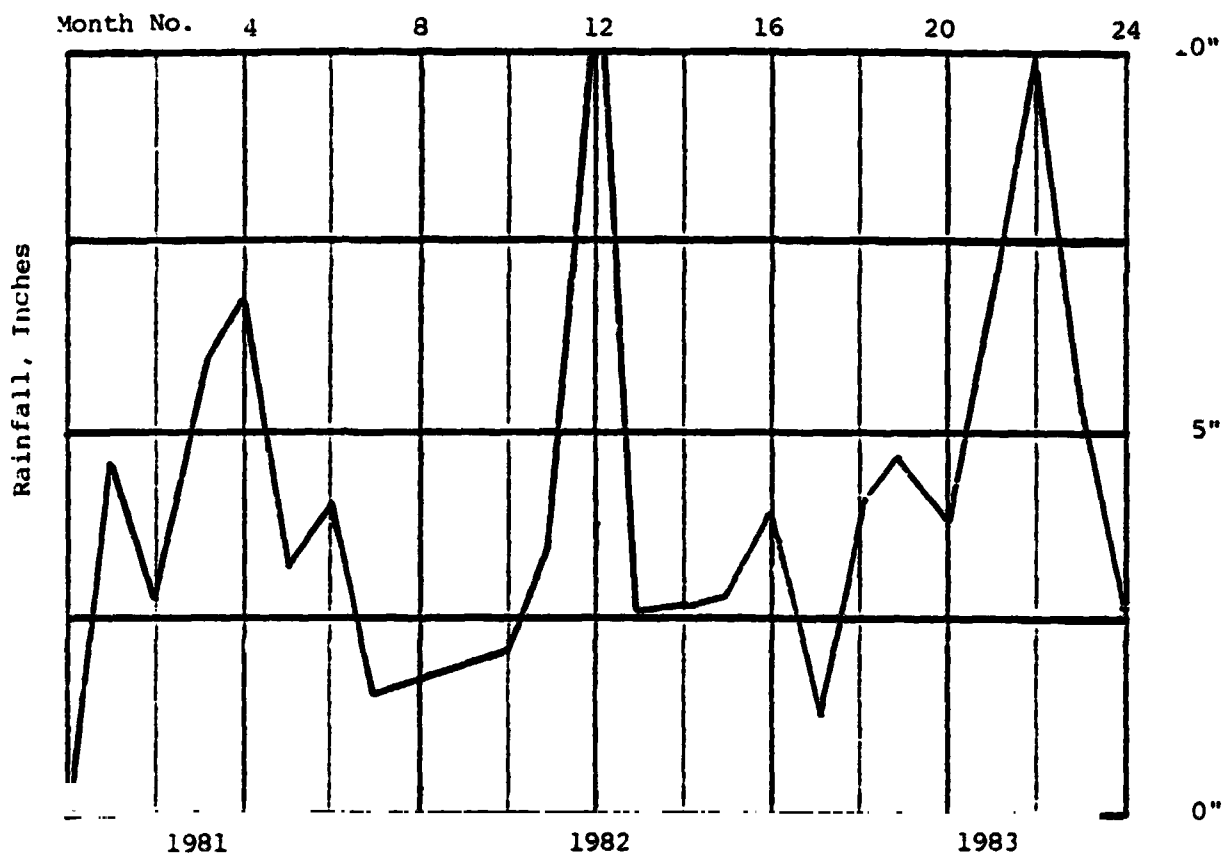
FIGURE 8

ORIGINAL PAGE 19  
OF POOR QUALITY

Soiling Experiments

Rainfall, Inches

Enfield, Connecticut



Rainfall Data, Inches

1981

Month No.	1	2	3	4	5	6
Inches	4.7	2.9	5.9	6.7	3.3	4.0

1982

Month No.	7	8	9	10	11	12	13	14	15	16	17	18
Inches	1.5	*	*	2.23	3.4	13.1	2.6	2.7	2.9	3.6	3.8	1.3

1983

Month No.	19	20	21	22	23	24
Inches	4.7	3.8	6.7	10.1	5.3	2.6

\*Indicates no rain, only snowfall during this time.